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THE METALLOGRAPHY OF ALUMINUM.*

BY

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I. INTRODUCTION.

ALUMINUM is the lightest of the commercial metals which are used in large quantities, having a density of 2.702 ±; once obtained in ingot form, it can be worked and fabricated with moderate ease; metallographically, it is one of the most interesting of any substantially pure metal known; from the physico-metallurgical standpoint, very little is known about it. Aluminum has usually been assigned by metallographic writers to the isometric system, but late research has shown it to be tetragonal (1, 2)[1]. The remarkable method of crystal analysis developed by Laue and the Braggs and modified by Hull has shown that the unit of structure of aluminum is a centred rectangular prism with square base 2.85 angstroms by 2.85 angstroms and height 4.85, with an atom at each corner and one in the centre of the prism; the number of atoms per unit parallelopiped is two. The methods of X-ray analysis of Bragg (3) are applicable to individual crystals of appreciable size which are reasonably free from twinning, and developed sufficiently to permit the determination of the direction of their axes. Hull's method is a modification of Bragg's, and can be applied to all crystalline substances. Briefly, it consists in

* Communicated by the Author.

[1] References are to Bibliography.

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sending a narrow beam of monochromatic X-rays through a disordered mass of small crystals of the substance whose crystal habit is to be determined and then photographing the diffraction pattern produced. Aluminum has not, in general, been regarded as allotropic, but the available evidence would arouse suspicion that it may be; such suspicion is based on the fact of greatly altered physical properties in the aluminum alloy duralumin on heat treatment, while Lashchenko (4) has found a thermal change at 580–590°C. Lashchenko noticed a break in the cooling curve of aluminum between 580 and 590°C., indicating transformation into an allotropic variety, the change being accompanied by a thermal effect of 3.5 calories per gram of aluminum. Cohen (5) found that the specific-heat-temperature curve was not continuous. Whether aluminum is allotropic or not still remains to be shown with an abundance of unmistakable data.

As I have said many times before, information on the metallography of aluminum is almost negligible—in fact, the metallographic study of this metal may be said to have just begun. A reasonable amount of metallographic investigational work has been performed with great diligence by the Alloys Research Committee of the Institution of Mechanical Engineers (56, 57, 58) on the aluminum-rich alloys of commercial importance; *viz.*, aluminum-copper, aluminum-copper-manganese, and aluminum-zinc alloys. A series of recent papers (6) has given valuable data in compact form on the physical properties of aluminum, to which reference may be made for particular information.

Off-hand, it may appear desirable, in view of what has just been said, to confine the present paper to a description of the microstructure of various forms of aluminum, but a moment's reflection will render it evident that it will be better to briefly discuss also our fundamental metallographic notions, so that the metallography of aluminum may be considered in terms of modern conceptions and interpreted in relation to other metals. Accordingly, the present paper will consist of a brief discussion of the amorphous theory and plastic deformation, with some remarks on grain growth phenomena; while the microstructure of various forms of aluminum, cast, worked, and annealed, will be treated in greater detail. The annealing and recrystallization of aluminum which has had plastic deformation will be described

at some length, and there will be included a section on exaggerated grain growth in deformed aluminum, together with a short note on the polishing and etching of aluminum microsections preparatory to microscopic examination.

II. THE AMORPHOUS THEORY AND PLASTIC DEFORMATION.

As is well known, substantially pure metals in the solid state consist of a greater or less number of allotriomorphic grains or crystals. Crystallographically, such crystals are referred to as allotriomorphic (not idiomorphic), since their shape is determined by neighboring crystals, but metallographers prefer, usually, to call them simply grains. Liquid pure metals are held to be amorphous, since their molecules are not arranged in any systematic way. When the temperature of a liquid metal is lowered to the freezing point, crystallization commences from various nucleii. Without taking time now to examine the mechanism (7) of freezing and crystallization, the ultimate structure of a frozen metal consists of an aggregate of grains, each one of different orientation than its neighbor; the regular allotriomorphic structure normally results unless there are specific conditions under which the rate of cooling or the presence of impurities is such as to give rise to a cellular or dendritic structure. Metals and alloys are found to be widely different in physical properties (in the same metal or alloy), depending upon whether they are cast, worked, or annealed, and among all the theories submitted to account for the existing differences, that laid down by Beilby (10) and elaborated upon by Bengough (11), Rosenhain and Ewen (12), and Rosenhain (13) has the largest number of adherents among metallographers.

Beilby's Amorphous Theory.—Beilby demonstrated some time ago that during the ordinary operations of polishing a sample of metal an amorphous surface film is produced. In essence, Beilby's theory submits, and this is now generally accepted, that when a metal undergoes plastic deformation the various sections of the individual grains slip along their gliding or cleavage planes and by so slipping generate amorphous metal at these planes. Further, it is believed, that amorphous metal is also generated at the grain boundaries, during plastic deformation. This generation of amorphous metal makes a worked metal stronger and harder than an annealed metal because the amorphous phase

is stronger and harder than the crystalline phase; the amorphous phase is assumed to be entirely non-plastic. The amorphous phase is that of minimum thermal stability and maximum mechanical stability, while the reverse is true of the crystalline phase; thus, the effects of heat are to change amorphous metal into crystalline. In accordance with this theory, then, it is found that when the elastic limit of a metal is exceeded and plastic deformation begins to act, slipping takes place along the cleavage or gliding planes of the individual crystals, resulting in a relatively high temperature localized at the slipping planes. At the temperature so produced the slipping action generates amorphous metal according to

$$\text{Crystalline} \rightleftharpoons \text{Amorphous}$$

and the amorphous metal so generated acts in the manner of a lubricant to promote slip. Whether the temperature is high enough to actually melt small particles torn away by the slip or not, the metal at the slipping planes is for a moment very mobile; the mobile metal does not so remain long, but passes into the hard, amorphous state, which is stronger and harder than the crystalline. Those portions where amorphous metal has been generated are stronger than other portions where no slip has occurred, and with further deformation the metal is amorphized more—the deformed piece becoming harder and stronger with the increase in amount of the amorphous phase.

Amorphization in a metal undergoing plastic deformation eventually comes to an end; it is not held possible to convert all of the crystalline phase into the amorphous, since comparative brittleness finally sets in, and the metal breaks. Most of the phenomena of the plastic deformation of metals can be readily explained by the above theory, which preceded Rosenhain's amorphous cement theory. Other theories have been advanced to account for the phenomena under discussion, some of which can be interpreted in terms of the amorphous theory, while others appear to be non-applicable.

Rosenhain's Amorphous Cement Theory.—Rosenhain and Ewen (12) and Bengough (11) have strongly advocated the existence of an amorphous cement at the boundaries of a frozen metal. According to this theory, the crystals of a pure metal are surrounded and cemented together with a very thin layer of the same metal in the amorphous state. This amorphous cement

is presumed to arise from the assumption of an indivisible crystal unit, and that during the formation of a crystal, crystalline material is added unit by unit, each unit consisting of several molecules. At the moment of final freezing the space between grains is too small to allow crystallization of the liquid metal there, since the space is not large enough to contain a crystal unit. Accordingly, the metal at the grain boundaries will remain in the amorphous state because the molecules will not have arranged themselves with the change of position accompanying crystallization for the particular metal. The existence of an amorphous cement explains many observed facts with reference to the physical properties of coarse- and fine-grained metals; however, if we hold with Bragg that crystal units are of less than molecular dimensions, then some difficulties arise with the amorphous cement theory. Lately, Rosenhain appears to have accepted the Bragg belief as to the size of crystal units. The evidence, however, submitted in favor of the existence of an amorphous cement includes: (1) the greater loss by volatilization on heating *in vacuo* from fine-grained than coarse-grained zinc, copper, and silver; (2) the intergranular fractures yielded by gold, tin, lead and bismuth at temperatures just below their melting points; and (3) the more rapid attack of etching reagents on the grain boundaries.

Quincke's Foam-Cell Hypothesis.—Prof. Georg Quincke (14) has advanced an interesting theory to explain the crystallization of metals. According to Quincke, the first step in the process of crystallization of a liquid is the separation of the liquid into two immiscible liquid phases, of which one is in subordinate amount to the other. This liquid arranges itself in a manner, often seen in immiscible oils and aqueous solutions, to form the walls of foam cells filled with the liquid which is present in greater amount. The arrangement of the crystalline particles when solidification takes place is determined then by the presence, size, and form of the foam cells. Referring in particular to metals, it is alleged that the crystal grains are the foam cells, and the boundaries of the grains are the foam walls. Hence, coalescence on annealing is held to be a manifestation of a foam to become coarser, this being interpreted to fit the case where small grains coalesce to form large ones. Other evidence in favor of foam cells is pointed out; *viz.*, the more rapid corrosion of the

grain boundaries on etching is supposed to result from the difference in composition of the foam walls and the foam cells; and in the same way the more rapid volatilization of the grain boundaries on heating *in vacuo* is explained. However applicable Quincke's theory may be to the study of emulsions and liquid crystals, it looks as though the foam theory postulates entirely too much when the attempt is made to apply it to metals.

Rosenhain's critical discussion of Tammann's objections to the amorphous cement theory has been sensible and instructive, and it is noticeably free from the labored attempts to adapt the theory to a certain scheme, as is the case with Quincke's theories.

Cold-Worked vs. Annealed Metal.—Microscopically, it is usually easy to distinguish worked from annealed metal, and there are, further, many differences in physical properties between any metal in the cold-worked and annealed conditions. The cold-worked metal has greater elastic limit and ultimate strength, and less elongation; the reduction in area of a cold-worked metal is usually less. Cold-working, resulting in permanent deformation, causes increased hardness, and in many cases increased density, though further cold work may again decrease the latter. A cold-worked metal, *i.e.*, one which has been permanently deformed below the temperature at which complete recrystallization takes place, consists of films of the amorphous phase in contact with the crystalline, whereas an annealed metal is practically physically homogeneous. In the foregoing it has been said that it is not possible to completely amorphize a ductile metal by work; for instance, it has been shown by Beilby that when a ductile metal is severely worked, as in wire drawing, where the metal is drawn repeatedly through smaller and smaller dies, that the distorted grains, even though enormously elongated, retain a crystalline core encased in an amorphous shell. In the cold rolling of ductile aluminum we have exfoliation of fine scales and thin films, indicating localized peeling away by fracture of small portions of the partly amorphized surface.

Amorphous metal is more electro-positive than crystalline metal (15), as can be shown by measuring the difference in potential between annealed and cold-worked samples of the same metal. Cold-worked metals are then both more electro-positive and more heterogeneous physically than otherwise identical annealed metals. The electric conductivity of a cold-worked metal is

less than that of an annealed one, while of the heat of solution the reverse is true.

Plastic Deformation.—Deformation, below the temperature of recrystallization, of a ductile metal, by such mechanical processes as rolling, forging, drawing, and the like, greatly alters its physical properties. We have seen that metals are granular, and we have now to touch briefly on the effect of deformation on the crystalline structure of metals. Any stress within the elastic limit of a metal results in an elastic deformation, from which the metal recovers completely upon release of the stress. Stress exceeding the elastic limit results in plastic deformation, recognized as a permanent set, and at the same time increases the elastic deformation. Plasticity in a ductile metal is marked by the ability which it has for passing through a relatively weak phase and into a strong phase; the strong phase is held to be amorphous and does not return to the weak phase unless recrystallization is effected. The changes in physical properties by plastic deformation are those which must necessarily follow from amorphization, as has already been shown, and Beilby's theory very satisfactorily explains the mechanism of such deformation.

III. SOME OBSERVATION ON GRAIN GROWTH PHENOMENA.

The mechanism of grain growth in metals has lately been subjected to conditions of careful experiment, and in the past few years considerable data have been assembled to explain this phenomenon. I may mention in passing that the determination of grain size as a routine procedure in works laboratories has not been deemed so important as it was once thought it would be. A few remarks on grain growth in metals may be properly included in the present paper since it will be well to have the main points in mind when discussing exaggerated grain growth in aluminum, to be taken up in a later section. Rapid cooling of metals is conducive to fine-grain size, whereas slow cooling results in relatively coarse grains; largest grains, in a cast metal, are the result of holding the metal for a long time at or near the freezing point. Grain size in worked and then annealed metals depends upon the amount of prior plastic deformation, and the annealing conditions (time of exposure and temperature). The physical properties of metals are connected intimately with the grain size, and its influ-

ence can be readily understood on the basis of the amorphous cement theory (11, 12, 13).

The smaller the grain size of any given metal, the greater the amount of amorphous cement between the grains; therefore, the fine-grained metal, having more of the strong cement than a similar coarse-grained metal, is stronger. The fine-grained metal has greater ultimate strength and elastic limit than a coarse-grained metal, and also higher elongation. Further, the fine-grained metal stands up better under shock and fatigue. Smoothness of surface is an important requisite in sheet metal for industrial drawing operations, and a definite minimum grain size will insure surface smoothness (28).

Metals and metallic alloys may be subjected to plastic deformation, and, under definite conditions, recrystallization and grain growth ensue on annealing. The temperature of most rapid growth is a function of the amount of deformation—which implies that for a certain definite deformation there is a critical temperature at which grain growth proceeds with the greatest rapidity. This temperature of fast growth is definite, within certain limits, and any greater or less temperature for a particular deformation will result in less rapid growth. This leads to a consideration of the important germinative temperature phenomenon which was advanced in its present form by Jeffries (29) and elaborated upon by Howe (30).

Germinative Temperature Phenomena.—Broadly stated, a given set of grains which do not grow in the cold will commence to grow on heating to a certain temperature, and will continue to grow at all higher temperatures. The so-called germinative temperature is defined as that temperature at which growth begins. There accordingly exist two temperature ranges with reference to the germinative temperature; *viz.*, (1) an inert range below it, and (2) a growth range above it. In the event that only part of a differentially strained piece of metal is at the germinative temperature, this becomes the fast-growth temperature for that particular part, and the germinant grains grow by boundary migration, feeding on the adjacent inert grains. In such instance, we have the greatly exaggerated growth of Sauveur (32), Chappell (33), Jeffries, *et al.* Similar exaggerated growth has been observed by the present writer (34) in the case of aluminum, which is more fully described in this paper. The

late results of White and Wood (38) indicate that germination is not alone dependent on temperature, but that it may occur after a relatively long exposure at a temperature which would not bring it about after a short exposure.

Grain growth is influenced, among other things, by the fineness of grain, by the grain-size contrast, and by the amount of prior plastic deformation; these factors also affect the position of the germinative temperature. Temperature is a leading factor, and grain growth proceeds more readily at higher temperatures. On the other hand, growth is opposed by obstructing material such as cementite, slag, and other sonims in iron, and by thorium oxide in tungsten, as well as by the decrease in the grain-size contrast. For the reasons just given, the germinative temperature is raised. There is, of course, no growth on annealing unless there has been prior deformation. It has been found by Jeffries that although a long sojourn at a low temperature might result in exaggerated growth, a rapid heating to a high temperature might prevent it.

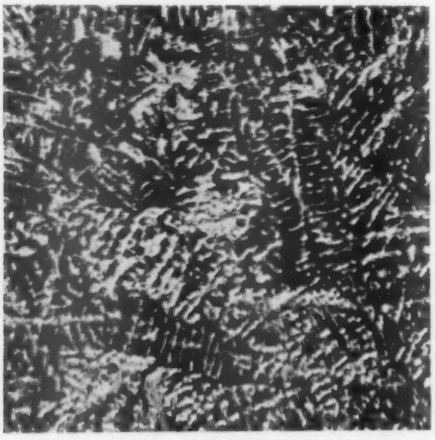
IV. THE INTERNAL STRUCTURE OF CAST ALUMINUM.

The crystalline character of metals was noted in the seventeenth century by Hooke (9) in connection with the microscopic study of fractured surfaces, and subsequent observation has shown that all metals are crystalline. When cast from the liquid state and cooled moderately slowly, substantially pure aluminum consists, like other metals, of an aggregate of allotriomorphic grains. No reports of idiomorphic crystals of aluminum have come to hand. Aluminum, however, readily forms dendritic crystals on solidification, and some instances have been observed of very striking dendritic structure. The best commercial aluminum is far from pure, ordinarily, when compared to the relatively high state of purity in which commercial copper, zinc, and tin are obtainable. This lack of purity does not, however, prove a handicap, except in special cases, to the utilization of the metal. An aluminum containing 0.15 per cent. Cu, 0.30 per cent. Fe, 0.30 per cent. Si, and 99.15 per cent Al (by difference) represents a fairly good commercial product at this writing. Metal containing up to 99.60 per cent. Al has been produced. The influence of the impurities iron and silicon is now believed to be more profound than was hitherto generally held, and there

seems to be a very important relationship existing between iron and silicon, and between these elements and the aluminum itself, which, not only affects the properties of the metal but even of its alloys. Just what these relationships are is not known with certainty.

Condition of the Impurities.—In an aluminum of the analysis given above, if slowly cooled, the entire amount of copper is in solid solution; aluminum dissolves up to about 4.5 per cent. Cu in the solid state at 15°C. The iron forms an aluminum-iron compound, $FeAl_3$, which is but slightly, if at all, soluble in the solid state; while the silicon is present, probably entirely, as

FIG. 1.



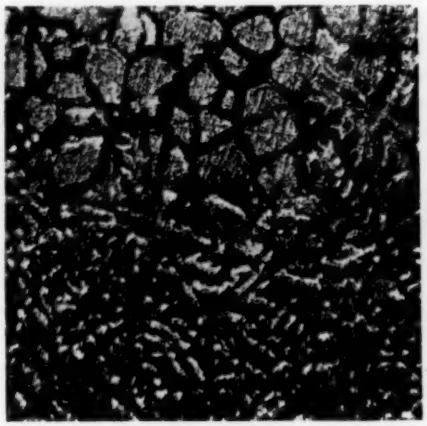
Chill-cast pig aluminum; dendritic structure; × 40.

elemental silicon. Silicon can exist in aluminum in two forms; (1) as crystals of free silicon, and (2) in solid solution. In cold-rolled sheet aluminum, silicon is present to a considerable extent as free silicon, but on annealing the silicon appears to go into solid solution to a degree.

Microstructure.—Turning now to an examination of the internal structure of substantially pure cast aluminum, reference may be made to the micrographs in Figs. 1 to 6 inclusive. Fig. 1 is a micrograph of chill-cast pig aluminum, the photograph having been taken at a point near the edge of the ingot; the structure is plainly dendritic (55). Fig. 2 is a micrograph of the same metal, but the photograph was taken at a point a little farther in

towards the centre of the ingot where the structure is allotriomorphic; in this micrograph is shown the juncture of the dendrites and the allotriomorphic grains with one type of structure passing abruptly into the other. Fig. 3 shows the structure of deeply etched aluminum cast in a chill mould; the structure tends to be cellular. Fig. 4 illustrates at high magnification the microstructure of sand-cast aluminum, cast in the form of a tensile-test bar, while Figs. 5 and 6 are aluminum where the microsections were taken from gates in a sand casting. Unless otherwise indicated throughout this paper, the aluminum referred to as substantially pure metal means aluminum analyzing over 99 per cent.

FIG. 2.



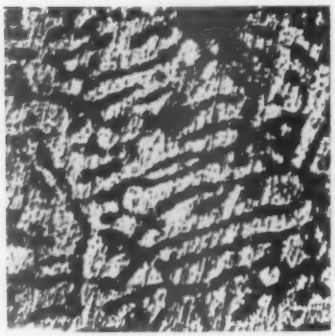
Juncture of dendrites and allotriomorphic grains in chill-cast pig aluminum; × 40.

Al, with the usual impurities, iron, silicon, and copper. The microstructure of aluminum in the cast condition is relatively simple; the structure consists of the grains of aluminum with the copper in solid solution and $FeAl_3$ segregated to the grain boundaries; the silicon when free appears to be both intra- and inter-granular. Not much pure aluminum as such goes into the production of castings, since the metal is ordinarily used in the form of an aluminum-rich alloy in the foundry. Most of the pure aluminum cast into ingots goes into the manufacture of sheet, wire, rods, bars, etc. The cast aluminum alloys are in general easier to etch for microscopic examination than is the metal itself.

V. ANNEALING AND RECRYSTALLIZATION OF COLD-WORKED ALUMINUM.

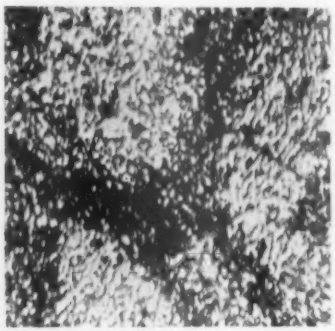
In brief, the effect of annealing cold-worked metals in general is to undo the internal changes set up by deformation—the result of annealing being, roughly, the restoration of the metal to its original crystalline condition, provided suitable precautions as to temperature and time of exposure for any given metal are observed. The first noticeable effect of heating cold-worked metal is the production of a small, but still readily detectable, increase in hardness, as has been shown by Mathewson, Thompson, *et al.*, and further heating causes softening; also, if the heating is sufficiently prolonged at a high enough temperature, the

FIG. 3.



Substantially pure aluminum; from centre of web of notch bar; × 78.

FIG. 4.



Sand-cast aluminum; from tensile bar; × 455.

strained metal will become dead soft. Softening, as evidenced by the customary hardness tests, has been intimately associated with recrystallization, but this does not follow *per se*, as has been pointed out by Howe (31), for metals in general, and has been referred to by the writer for aluminum in particular (44). Going back to the slight increase of hardness observed after short exposure to heat in the case of cold-worked metals, recent observations have noted an increase of hardness in cold-rolled sheet aluminum after very short exposures.

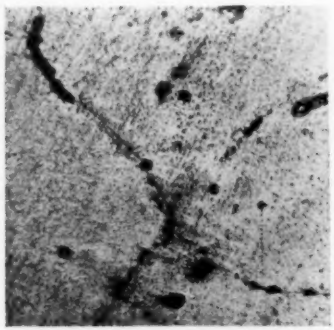
The first systematic account of the various relations existing among the factors percentage of reduction, the alteration in physical properties and microstructure, and the time of exposure and temperature of anneal was set forth by the French engineer C. Grard (49), scarcely ten years ago, for rolled copper and brass.

Further efforts in this direction have been extended by Bardwell for copper, Bengough and Hudson (50) for brass, Mathewson (48), and Mathewson and Phillips (42). The first account of the effects of heat at various temperatures on cold-rolled aluminum sheet was given only recently by Carpenter and Taverner (43), where unfortunately the percentage of reduction was not known, and still more unfortunately microscopy was not included. Elsewhere (44, 45, 46, 47), I have described the effects of heat at various temperatures on cold-rolled aluminum sheet of known percentages of reduction, as measured by the Erichsen ductility test and the Shore hardness; unfortunately also, microscopy was

FIG. 5.

Substantially pure aluminum; from gate in sand casting; etched with NaOH; ×75.

FIG. 6.



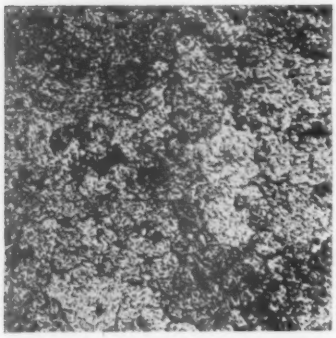
Substantially pure aluminum; from gate in sand casting; etched with NaOH; ×200.

not completed. In the present section of this paper are included micrographs showing the alterations in structure accompanying exposure to heat at various temperatures of sheet aluminum of known percentages of reduction. Positive proof is now at hand which shows that severely worked aluminum (say percentage of reduction above 50.0) can be practically completely softened as indicated by the scleroscopic drop without complete recrystallization occurring.

Rosenhain, in his book on physical metallurgy (25), has observed that aluminum is sluggish in recrystallizing, and this has also been confirmed by Brislee (51). Brislee, writing in a late paper (51) appears to tend toward the belief in an allotropic modification of aluminum, but no evidence is submitted. In the same paper he says: "The amount of cold work which can be

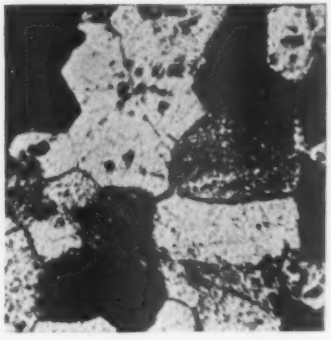
done upon aluminum is limited by the formation of the amorphous state. Microscopic examination of polished and etched specimens taken at various stages during cold working shows that the crystalline structure disappears at a very early stage in the working, and unless the metal is annealed it will become fatigued, developing a species of 'Forcierkrankheit.' Aluminum which has been subjected to excessive cold work shows an entire absence of structure, and has the appearance of a metal which has flowed and passed into a vitreous state. The reverse change takes place with extreme slowness, and the ordinary annealing process does not change the structure from amorphous to crys-

FIG. 7.



Shore H. N.—5.0. Hot-rolled, 0.25-inch aluminum slab; × 100.

FIG. 8.



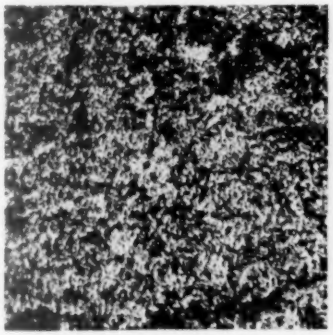
Shore H. N.—4.0. Hot-rolled, 0.25-inch aluminum slab; after 10-minute anneal at 595° C.; × 100.

talline. Aluminum annealed at a temperature of 500°C. for ten hours appears to be 'dead soft,' and has its maximum elongation; nevertheless it is still largely amorphous in structure when examined microscopically. Aluminum which has been annealed in this way hardens very rapidly when additional cold work is done upon the metal. The primitive crystals are transformed into the amorphous state much more readily than the larger crystals which are developed by annealing. The results of the specific heat determinations render the conclusion probable that under the influence of cold work aluminum is transformed into an amorphous variety."

Seligman, in a discussion of the above, claims that he does not follow all of the arguments and does not confirm that as a general

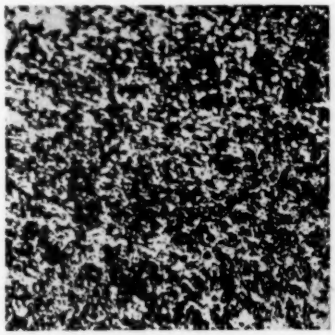
rule aluminum after ten hours' heating at 500°C. is largely amorphous in structure. The present writer does not entirely agree with Brislee's observations; however, the general trend of his remarks appears to accord with the known facts. Matweef (52) hardened aluminum by cold-hammering and afterwards annealed for five minutes at various temperatures; he concluded that aluminum did not begin to lose the work hardness so conferred until the definite temperature 350°C. had been reached. Rose (53) found that an impure aluminum containing 2.1 per cent. iron when in the cold-rolled condition had a scleroscopic drop of from 25 to 6, magnifier hammer (or 14 to 3.4, regular hammer)

FIG. 9.



Shore H. N.—15.0. Reduction—63.3 per cent. Cold-rolled, 12-gauge aluminum sheet; × 100.

FIG. 10.



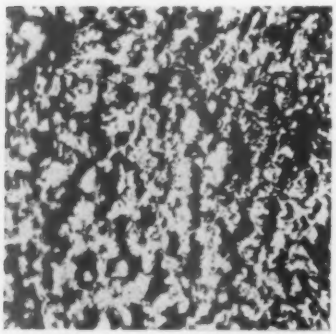
Shore H. N.—14.0. Reduction—71.6 per cent. Cold-rolled, 14-gauge aluminum sheet; × 129.

after a 30-minute exposure at 425°C. In a recent note on the annealing of aluminum (54), it was said that aluminum exhibits a certain sluggishness towards recrystallization, and it requires relatively higher temperatures, or longer times, or both, depending upon the amount of amorphous material present or the amount of deformation to bring about recrystallization, than would be expected. At the time the writer was not fully aware of the significance of the apparent wide range between the coalescence and softening zones of aluminum; it is true, however, that they are far apart.

Microstructure of Hot-Worked Aluminum.—Hot work as ordinarily conducted leaves aluminum in a state of greater or less strain, since the finishing temperature is usually not high enough

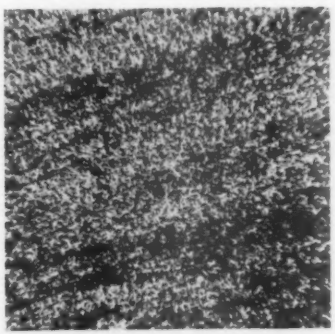
to effect self-annealing in the metal, *e.g.*, in a hot-rolled slab. The grains are left in a distorted condition, although the boundaries may be distinguished. This is illustrated by the micrograph in Fig. 7, which shows the internal structure of a hot-rolled 0.25-inch aluminum slab. The history of the metal just mentioned is as follows: the slab was produced by breaking down a 4-inch thick ingot, which had previously been heated for six hours at 455°C., to 0.25-inch thick with five or six passes in a hot mill; cross-rolling was done in the later stages. Referring to Fig. 7, it will be seen that grain boundaries can be readily distinguished, but that the individual grains are considerably distorted by the

FIG. 11.



Shore H. N.—14.0. Reduction—71.6 per cent. Cold-rolled, 14-gauge aluminum sheet; ×370.

FIG. 12.



Shore H. N.—14.5. Reduction—82.6 per cent. Cold-rolled, 18-gauge aluminum sheet; ×75.

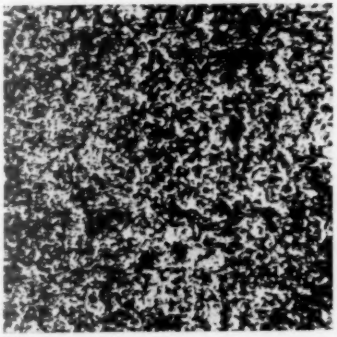
work. The effect of annealing at an appropriate temperature and for sufficient time is to cause recrystallization, as is illustrated in Fig. 8—a micrograph showing the internal structure after a ten-minute exposure at 595° C. The sample from which Fig. 8 was taken was etched rather deeply; such etching would be undesirable for grain-size determinations, since for this the boundaries should be developed sharply.

In the commercial production of sheet aluminum the metal is at first worked hot, and the final rolling to finished gauge is performed cold; the commercial reductions in the mill are often quite high, being, for some of the lighter gauges, up to 95 per cent. total reduction. This reduction is, of course, not all accomplished in one pass, but the metal is reduced gradually. Sheet aluminum so

made is subjected to plastic deformation, and the amount of reduction is a very important factor in governing subsequent annealings.

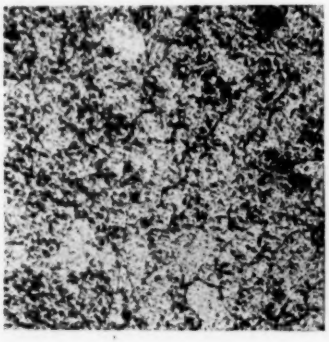
Microstructure of Cold-Rolled Aluminum.—When aluminum is rolled in the cold the deformation produces a certain amount of amorphous metal due to the slip of the individual grains as already outlined. Cold rolling of aluminum results in partial amorphization, where the individual grains are first elongated and then broken up, amorphous metal being formed; when examined under the highest available powers of the metallographic microscope, it is impossible to detect anything suggestive of

FIG. 13.



Shore H. N.—14.0. Reduction—88.0 per cent. Cold-rolled, 22-gauge aluminum sheet; × 200.

FIG. 14.



Shore H. N.—5.0. Reduction—63.3 per cent. Twelve-gauge aluminum sheet; after 60-minute exposure at 350° C.; × 100.

crystallinity in hard-worked aluminum. By hard-worked aluminum, in general, is meant that which has had fairly large reduction. The internal structure of aluminum in this form is typically amorphous and flow lines in the direction of work are at times distinguishable. Micrographs in Figs. 9 to 13 inclusive show the internal structure of different samples of aluminum sheet, which had various reductions. By examining the micrographs closely, no evidence of crystalline structure can be found, and the metal is said to be amorphous. In the micrographs, indications of grain boundaries are still evident in Fig. 9, where the percentage of reduction was 63.3, but with increasing reduction these disappear. Indications of the direction of work are noticeable in Fig. 12.

The changes in microstructure which accompany exposure to

heat in the case of cold-rolled aluminum are interesting, if difficult to interpret, and micrographs in Figs. 14 to 44 inclusive are included to show these changes. Annealings were made at various temperatures and for various times on samples of cold-rolled sheet aluminum of the following analysis:

Cu	0.25 per cent.
Fe	0.45 per cent.
Si	0.35 per cent.
Al	98.95 per cent. (by difference).

The softening effect of anneal was measured with the Shore scleroscope, and the microstructure was examined. In the micrographs, the percentage of reduction and the hardness after anneal are given for ready reference, and the summation of the results is tabulated in Table I.

TABLE I.

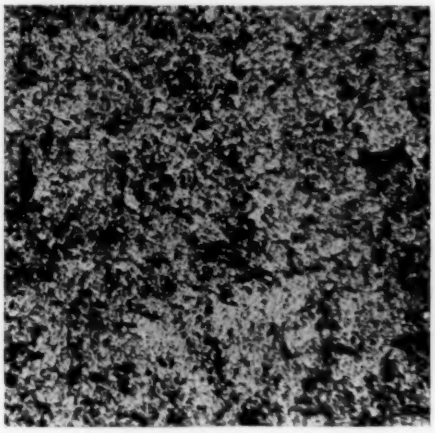
Effects of Heat at Various Temperatures on Cold-Rolled Aluminum Sheet of Different Percentages of Reduction.

Refer to figs.	As rolled		Heat treatment		Shore H. N. after anneal	Sheet gauge	Remarks
	Percentage of reduction	Shore H. N.	Time in mins.	Temperature in degrees C.			
14	63.3	15.0	60	350	5.0	12	
15	63.3	15.0	60	400	4.6	12	
16	63.3	15.0	10	600	4.4	12	
17, 18	71.6	15.0	6	400	6.0	14	
19, 20	71.6†	11.5	10	400	6.0	14	Was ½ hard.
21	71.6	14.0	1440	370	4.0	14	Mill anneal.
22, 23	77.7	15.0	5	350	6.0	16	
24, 25, 26	77.7	15.0	240	525	5.0	16	
27, 28	80.0*	14.0	30	400	5.5	17	
29	80.0*	15.0	30	550–575	5.0	17	Furnace cooled.
30, 31	82.6	14.0	2	350	5.0	18	
32, 33	86.0	15.0	2	350	5.0	20	
34	86.0†	11.0	240	525	4.0	20	Was ½ hard.
35	86.0	15.5	30	550–575	5.0	20	Furnace cooled.
36, 37	88.0	15.0	1440	370	3.5	22	Mill anneal.
38	90.5	15.0	10	400	4.0	24	
39, 40	92.7	14.5	30	550–575	5.0	26	Furnace cooled.

* Approximately.
† Original reduction; this was within two gauge numbers of the finished gauge; the sheet was then annealed, and then reduced to gauge.

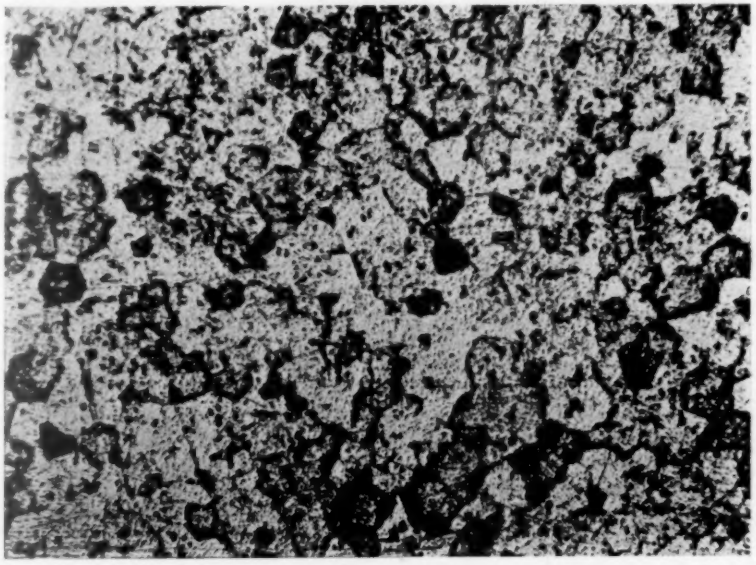
Alteration in Microstructure on Anneal.—A detailed discussion of the changes in internal structure accompanying annealing, with reference to Table I, will be given first, and some explanations will be offered later. Thus in Figs. 14, 15, and 16, which are

FIG. 15.



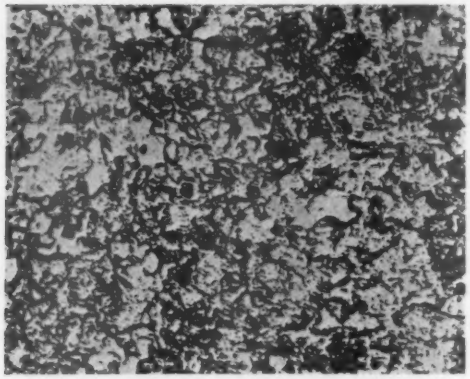
Shore H. N.—4.6. Reduction—63.3 per cent. Twelve-gauge sheet; after 60-minute exposure at 400° C.; × 100.

FIG. 16.



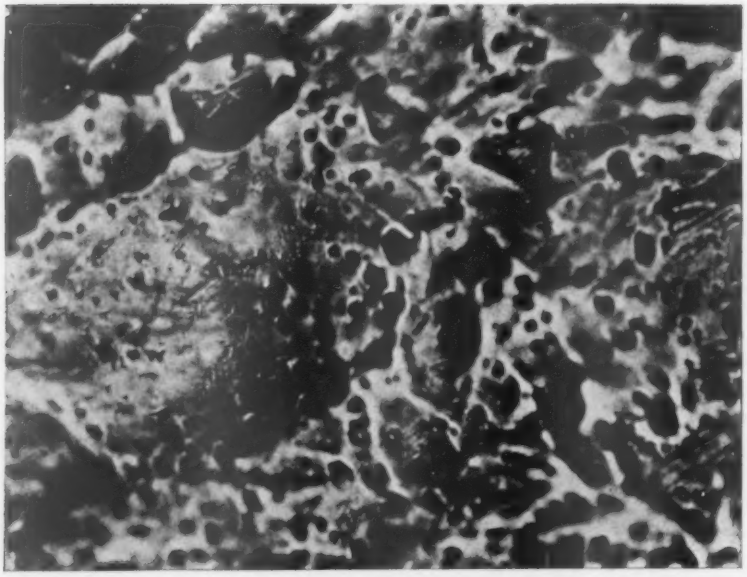
Shore H. N.—4.4. Reduction—63.3 per cent. Twelve-gauge sheet; after 10-minute exposure at 600° C.; × 100.

FIG. 17.



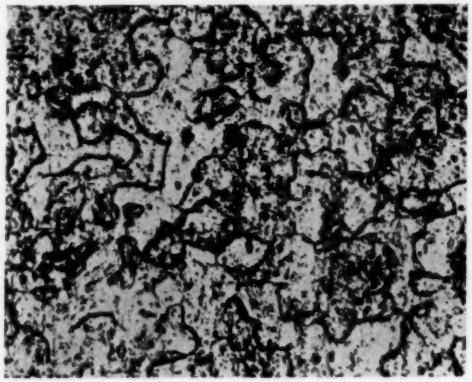
Shore H. N.—6.0. Reduction—71.6 per cent. Fourteen-gauge sheet; after six-minute exposure at 400° C.; × 100.

FIG. 18.



Shore H. N.—6.0. Reduction—71.6 per cent. Fourteen-gauge sheet; after six-minute exposure at 400° C.; × 1000.

FIG. 19.



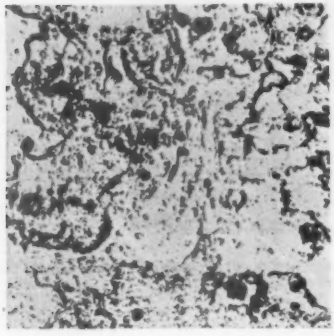
Shore H. N.—6.0. Reduction—71.6 per cent. (?); was half hard. Fourteen-gauge sheet; after 10-minute exposure at 400° C.; × 100.

FIG. 20.

Shore H. N.—6.0. Reduction—71.6 per cent. (?); was half hard. Fourteen-gauge sheet; after 10-minute exposure at 400° C.; × 1000.

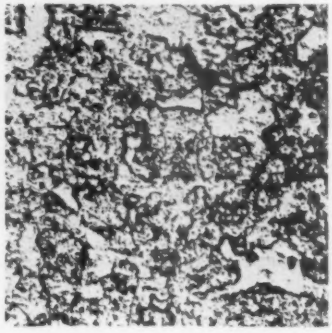
of 12-gauge cold-rolled sheet reduced 63.3 per cent., after various exposures at different temperatures, we find alteration in microstructure accompanying annealing, but there has apparently been no complete recrystallization. The scleroscopic drop was from

FIG. 21.



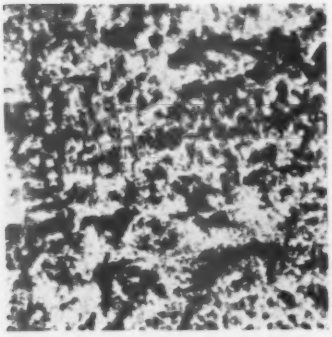
Shore H. N.—4.0. Reduction—71.6 per cent. Fourteen-gauge sheet; after 24-hour exposure at 370° C.; × 100.

FIG. 22.



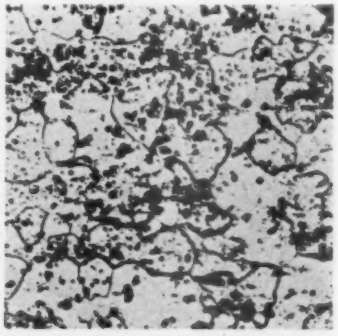
Shore H. N.—6.0. Reduction—77.7 per cent. Sixteen-gauge sheet; after five-minute exposure at 350° C.; × 100.

FIG. 23.



Shore H. N.—6.0. Reduction—77.7 per cent. Sixteen-gauge sheet; after five-minute exposure at 350 °C.; × 250.

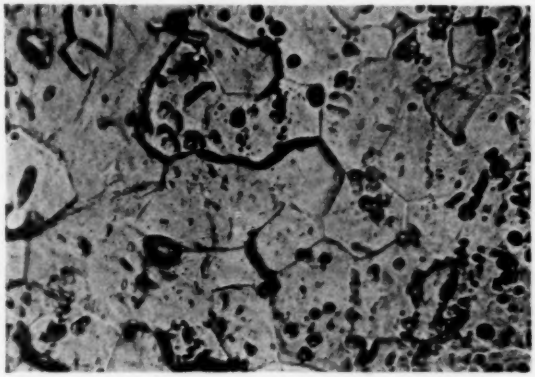
FIG. 24.



Shore H. N.—5.0. Reduction—77.7 per cent. Sixteen-gauge sheet; after four-hour exposure at 525° C.; × 100.

15 to 4-5, indicating practically complete softening. In Figs. 17 and 18 are shown the changes resulting from a six-minute exposure at 400°C. in the case of 14-gauge cold-rolled sheet, percentage of reduction 71.6; here again there has been considerable softening, as evidenced by the scleroscopic drop of from 15

FIG. 25.

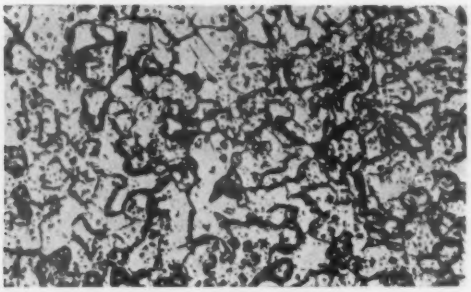


Shore H. N.—5.0. Reduction—77.7 per cent. Sixteen-gauge sheet; after four-hour exposure at 525° C.; × 100.

FIG. 26.

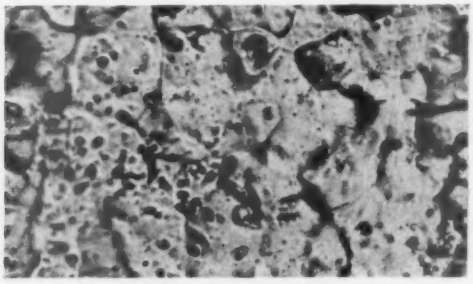
Shore H. N.—5.0. Reduction—77.7 per cent. Sixteen-gauge sheet; after four-hour exposure at 525° C.; × 1000.

FIG. 27.



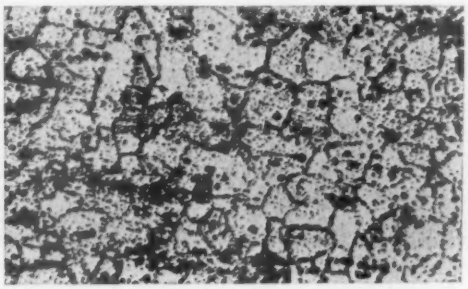
Shore H. N.—5.5. Reduction—80.0 per cent., approximately. Seventeen-gauge sheet; after 30-minute exposure at 400° C.; × 100.

FIG. 28.



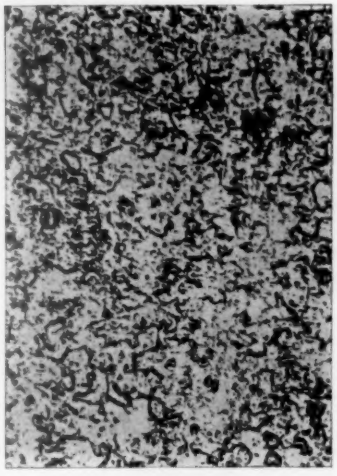
Shore H. N.—5.5. Reduction—80.0 per cent., approximately. Seventeen-gauge sheet; after 30-minute exposure at 400° C.; × 250.

FIG. 29.



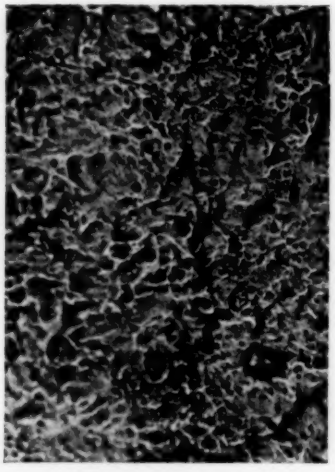
Shore H. N.—5.0. Reduction—80.0 per cent., approximately. Seventeen-gauge sheet; after 30-minute exposure at 550–575° C., and cooled with the furnace; × 100.

FIG. 30.



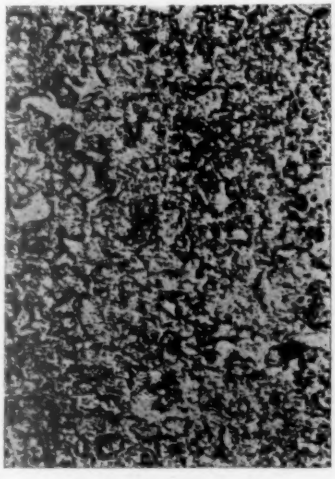
Shore H. N.—5.0. Reduction—82.6 per cent. Eighteen-gauge sheet; after two-minute exposure at 350° C.; × 100.

FIG. 31.



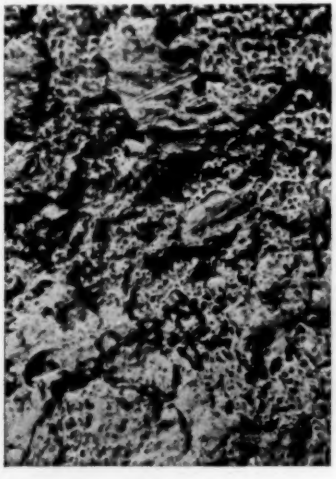
Shore H. N.—5.0. Reduction—82.6 per cent. Eighteen-gauge sheet; after two-minute exposure at 350° C.; × 250.

FIG. 32.



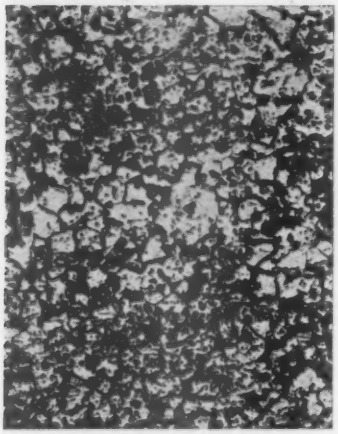
Shore H. N.—5.0. Reduction—86.0 per cent. Twenty-gauge sheet; after two-minute exposure at 350° C.; × 100.

FIG. 33.



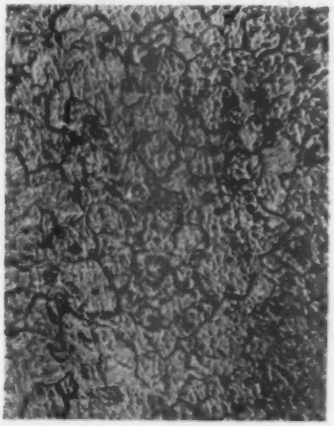
Shore H. N.—5.0. Reduction—86.0 per cent. Twenty-gauge sheet; after two-minute exposure at 350° C.; × 250.

FIG. 34.



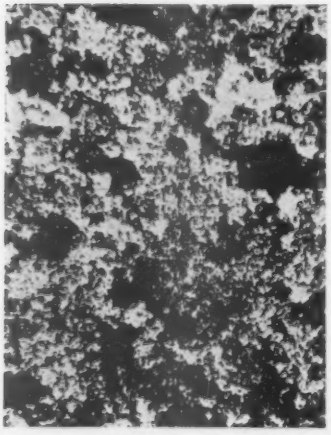
Shore H. N.—4.0. Reduction—86.0 per cent. (?); was half hard. Twenty-gauge sheet; after four-hour exposure at 525° C.; × 100.

FIG. 35.



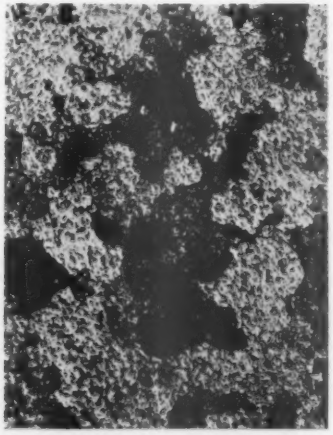
Shore H. N.—5.0. Reduction—86.0 per cent. Twenty-gauge sheet; after 30-minute exposure at 550–575° C., and cooled with the furnace; × 125.

FIG. 36.



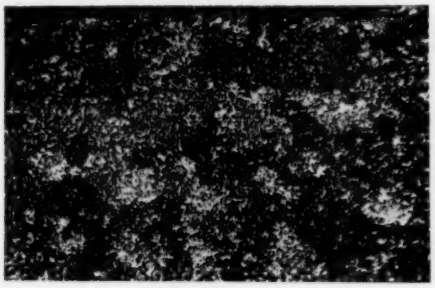
Shore H. N.—3.5. Reduction—88.0 per cent. Twenty-two gauge sheet; after 24-hour exposure at 370 °C.; × 50.

FIG. 37.



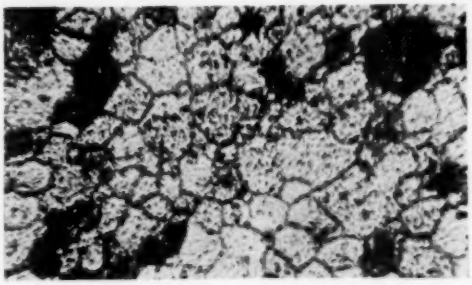
Shore H. N.—3.5. Reduction—88.0 per cent. Twenty-two gauge sheet; after 24-hour exposure at 370° C.; × 100.

FIG. 38.



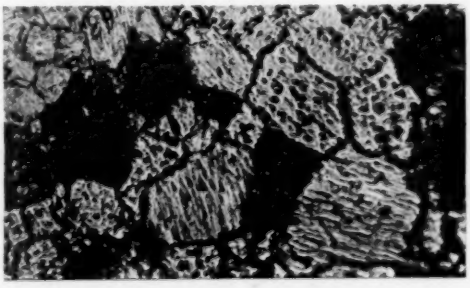
Shore H. N.—4.0. Reduction—90.5 per cent. Twenty-four gauge sheet; after 10-minute exposure at 400° C.; × 100.

FIG. 39.



Shore H. N.—5.0. Reduction—92.7 per cent. Twenty-six gauge sheet; after 30-minute exposure at 550–575° C., and cooled with the furnace; × 75.

FIG. 40.



Shore H.N.—5.0. Reduction—92.7 per cent. Twenty-six gauge sheet; after 30-minute exposure at 550–575° C. and cooled with the furnace; × 125.

to 6, and there has been alteration in microstructure, but no complete recrystallization. Figs. 19 and 20 show the alteration in microstructure resulting from a 10-minute exposure at 400°C. for so-called half-hard sheet; such sheet is manufactured by rolling cold within about two gauge numbers of the finished gauge and then annealing so as to make it dead soft; it is then finished to gauge with a few passes in a finishing mill. It will be seen that there is a greater tendency toward recrystallization here than in the previous case. A micrograph in Fig. 21 is that of cold-rolled 14-gauge sheet after a 24-hour exposure at 370°C.

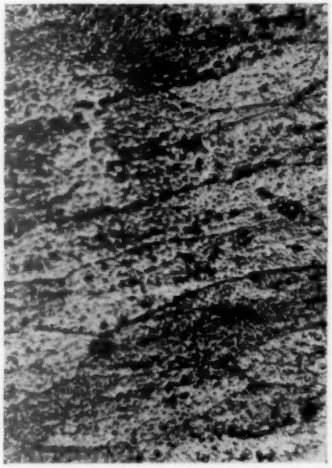
Annealings conducted on 16-gauge cold-rolled aluminum sheet with five-minute exposures at 350°C. and four-hour exposures at 525°C. give results in conformity with previous experience. The scleroscopic drop in the former instance was from 15 to 6, and in the latter from 15 to 5, but the samples annealed for the longer time and at the higher temperature were practically equiaxed, whereas the short exposure did not so result. It is now shown beyond any possibility of a doubt that the greater part of the softening occurs very rapidly in hard-worked aluminum, and to effect *complete* softening may take a very long time, depending upon the temperature. Comparison of Figs. 22 and 23 with Figs. 24, 25, and 26 should be made. Figs. 27, 28, and 29 show the internal changes set up by annealing 17-gauge sheets for 30 minutes at 400°C., and annealing for 30 minutes at 550–575°C. and cooling with the furnace, respectively. In the latter case, equiaxing has taken place, but in the former while there has been an alteration in microstructure it is not marked. In Figs. 30 and 31 are micrographs of 18-gauge aluminum sheet after a two-minute exposure at 350°C.; the percentage of reduction was 82.6 and the scleroscopic drop from 14 to 5; as in the above short exposures, there has been practically complete softening without recrystallization.

Exposures made on 20-gauge sheet for two minutes at 350°C. show the microscopic results in Figs. 32 and 33; Fig. 34 is the same metal after a four-hour exposure at 525°C.; and Fig. 35 is the same metal after annealing for 30 minutes at 550–575°C. and cooling with the furnace. It scarcely needs any clearer evidence than that so far given to show that the recrystallization of aluminum is exceedingly sluggish. Figs. 36 and 37 show the microstructure of 22-gauge sheet after a 24-hour ex-

posure at 370°C. Fig. 38 is a micrograph of 24-gauge sheet after a 10-minute exposure at 400°C.; while Figs. 39 and 40 are micrographs of 26-gauge sheet, percentage of reduction 92.7, after heating for 30 minutes at 550–575°C. and cooling with the furnace; in the latter, recrystallization is complete, and there has been grain growth.

Softening of Aluminum Without Recrystallization.—From the foregoing it is readily apparent that reorientation and grain growth are not cogent factors in the softening of cold-worked

FIG. 41.



Sixteen-gauge sheet; as received; elongated grains; × 215.

FIG. 42.

After annealing sheet in Fig. 41; 15-minute exposure at 540° C. and cooled with the furnace; × 100.

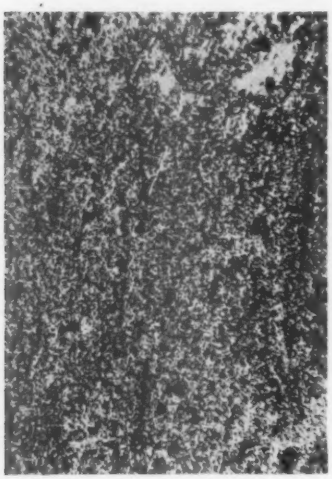
aluminum, and it is necessary to look elsewhere for the explanation of the scleroscopic drop, 14–15 to 4–5. Before making any inquiry into that, however, it may be advisable to reproduce micrographs showing perfect equiaxing and grain growth in sheet aluminum, to which I have briefly referred in another place (54). Fig. 41 is a micrograph of a sample of 16-gauge aluminum sheet, the history of which appears to be this: the grains had been equiaxed on anneal and then elongated by strain (note elongated grains in Fig. 41). Fig. 42 is the same metal after annealing for 15 minutes at 540°C. and cooling with the furnace. In the same way, Fig. 43 is typical of the structure of a 16-gauge

sample which had a Shore hardness of 8 as received, while after an exposure of 15 minutes at 540° C., followed by furnace cooling, the microstructure was as shown in Fig. 44. According to this, then, it appears that it is easier to recrystallize deformed aluminum on heating where there is the lesser amount of the amorphous phase. In other words, it seems that the amorphous phase is reluctantly transferable to the crystalline, in aluminum, and the change

$$\text{Amorphous} \longrightarrow \text{Crystalline}$$

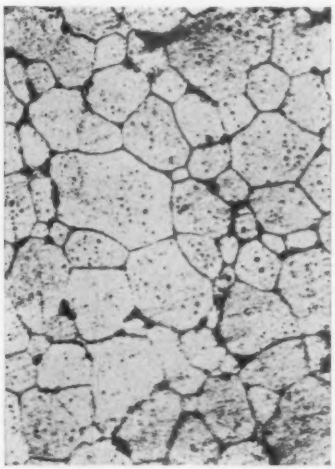
proceeds very slowly. Compare this now with the rapid re-

FIG. 43.



Sixteen-gauge sheet; as received; × 100.

FIG. 44.



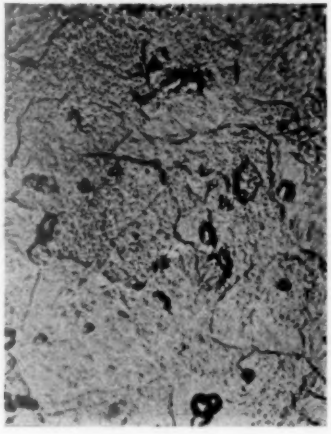
After annealing sheet in Fig. 43; 15-minute exposure at 540° C. and cooled with the furnace; × 100.

crystallization of copper, where an exposure for a few minutes or even seconds at 600–700°C. is sufficient to result in quite complete recrystallization. Whatever may be the explanation of why the amorphous phase of aluminum has such remarkable thermal stability is not readily apparent.

The view has been put forward by Howe (31) that stress relief and grain growth are not likely to contribute markedly to the softening resulting from heating deformed metal; that reorientation may be a contributory factor, but not the chief one; and that the reabsorption of the amorphous sheaths enclosing

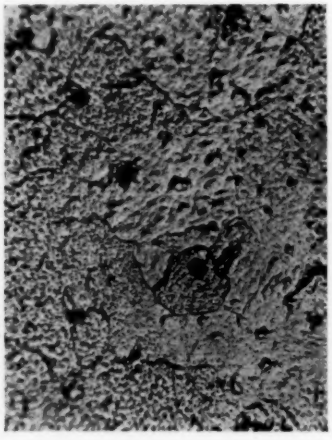
the fragments of grains, and a progressive change in the condition of these sheaths of the crystalline metal in those fragments are possibly important factors. Lest there be any possible doubt as to the interpretation of the micrographs in connection with the term "recrystallization," it is construed to mean reorientation and at least incipient grain growth; it is difficult, if not impossible to say just where the growth commences. There is no recrystallization in the instances cited above where short exposures bring about practically complete softening; there is unquestionably a change in the microstructure. The extreme difficulty in

FIG. 45.



Hot-rolled slab; average structure; × 215.

FIG. 46.



Hot-rolled slab; distortion due to cold-shearing; × 215.

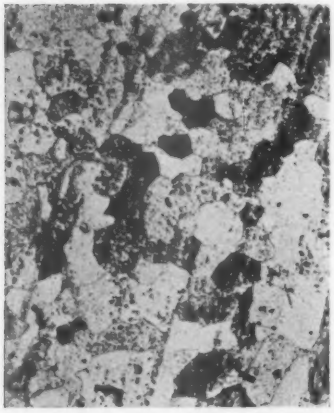
etching aluminum may, to a subordinate extent, account for some of the present trouble, but a comparison of the micrographs in Figs. 18, 20, and 26, under oil immersion, should suffice to remove any doubt as to the contention submitted. The effect of silicon and iron, as yet imperfectly understood, may be to retard growth, since it is conceivable that $FeAl_3$ might act as an obstruction.

VI. EXAGGERATED GRAIN GROWTH IN ALUMINUM.

Exaggerated growth in certain parts of a sample of metal which has had differential strain has been observed by Charpy, Le Chatelier, Sauveur, Chappell, Jeffries, *et al.* Observations

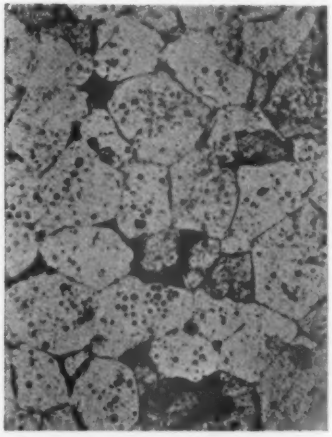
made have shown that local deformation such as results from a Brinell ball impression gives rise to exceedingly large grains in certain parts of the deformed area on annealing; this exaggerated growth has also been shown for strained tensile bars of iron. Space does not permit extended review of the above observations, nor is there any necessity for such review since the facts are now well known. In another place (34), I have called attention to certain recrystallization and grain growth phenomena in hot-worked aluminum, which had been differentially strained by cold shearing prior to annealing. Chappell's excellent paper (33),

FIG. 47.



Centre of microsection; after 10-minute exposure at 595° C.; × 50.

FIG. 48.



Centre of microsection; after 60-minute exposure at 595° C.; × 50.

which has been quoted many times, described exaggerated growth in deformed steel and iron where the deformation was the result of Brinnell impression and tensile strain. In the present section of this paper, description is given of exaggerated growth in aluminum, of the above analysis where the deformation was the result of cold shearing; this shearing set up differentially strained areas within a given sample.

Description of Experiments.—An aluminum slab, which had been hot rolled to 0.25-inch thick, was cold sheared along one edge with a mechanical power shear which cut the slab at a stroke. The force of shearing set up strain along the edge of the slab, and

the amount of strain was greatest near the edge and diminished in intensity in a direction perpendicular to the face of the sheared edge. The Shore hardness of the slab was 5, indicating practically dead-soft metal, although hot work had been done upon it; as just mentioned, the finishing was hot, probably in the neighborhood of 300–350°C., but this temperature is below the equiaxing temperature for aluminum so treated. The cold shearing caused local deformation and differential strain, the former occurring adjacent to the edge where the shear blade passed, and the latter varying in intensity inwards towards the mass of the metal. Microsections, taken from along the sheared edge, were exposed to heat for the times and temperatures given in Table II. Micro-

TABLE II.

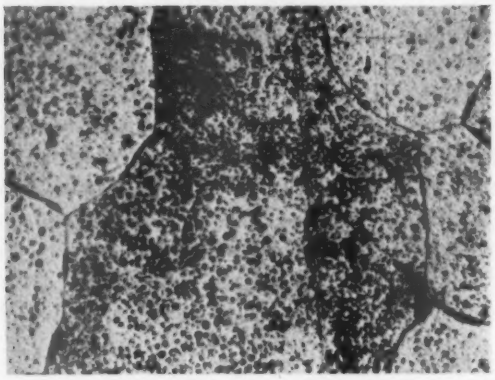
Exaggerated Grain Growth in Aluminum.

Refer to figs.	Heat treatment		Remarks
	Time in mins.	Temperature in degrees C.	
45, 46			As rolled.
47, 49	10	595	Not completely recrystallized.
48, 50	60	595	Fully recrystallized.
51, 52, 53, 54	240	595	Fully recrystallized.
55, 56	10	540	Not completely recrystallized.
	60	540	Fully recrystallized.
57, 58	10	485	Grain growth in part of section.
	60	485	Grain growth in part of section.
	10	425	None of these sections was recrystallized; there was no grain growth; the effects of annealing were apparent under the microscope.
	60	425	
	10	370	
	60	370	
	10	315	
	60	315	

graphs in Figs. 45 and 46 show the internal structure in the centre of the microsections and near the sheared edge, respectively. Grain boundaries are distinct in both micrographs, but the effect of work is evident, and the structure in Fig. 46 is more distorted than in Fig. 45 because of the strain near the edge. Figs. 47 to 58 inclusive illustrate the effects of annealing at various temperatures.

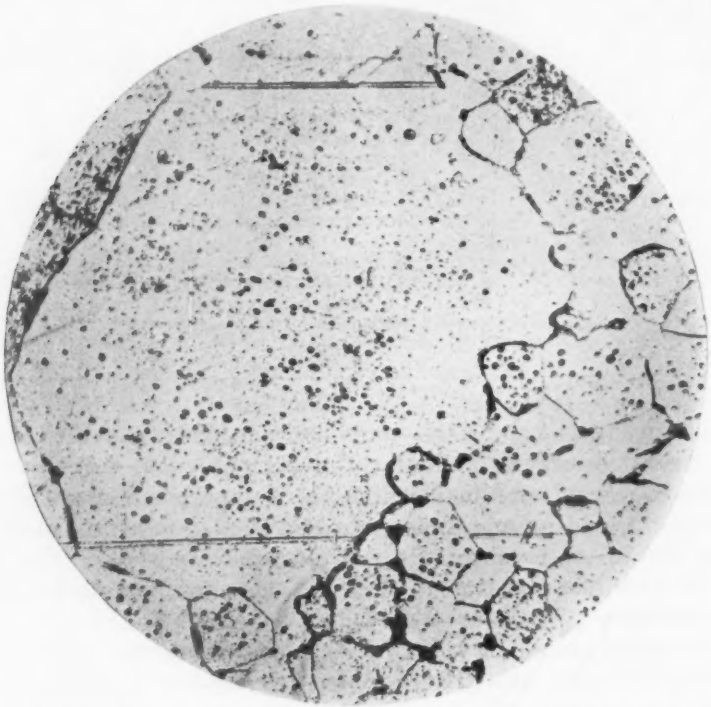
Turning now in detail to the changes in microstructure resulting from the heat treatment let us consider micrographs in Figs. 45, 47, and 48. Fig. 45 is the structure of the metal as

FIG. 49.



Enlarged grains in the portion of critical strain; after 10-minute exposure at 595° C.: × 50.

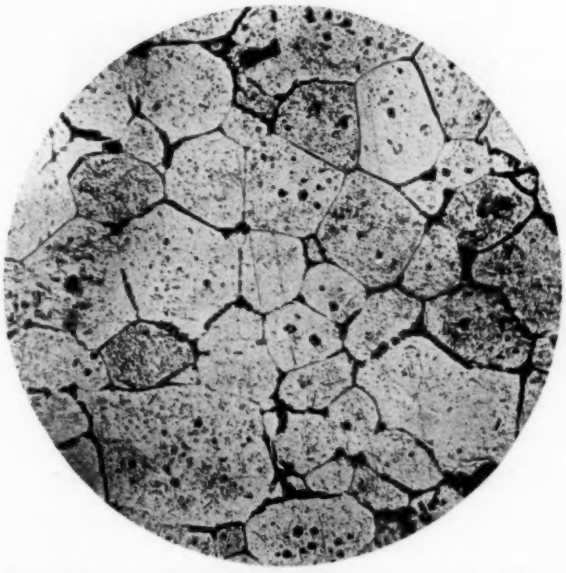
FIG. 50.



Juncture of large and small grains; after 60-minute exposure at 595° C.; × 50.

rolled, showing relatively small grains and distortion due to the hot work; the magnifications should be noted, since they were taken so as to best show the structure. Fig. 47 was taken at the centre of the microsection after an exposure of 10 minutes at 595°.C.; recrystallization is almost complete. Fig. 48 is a micrograph of the metal after a 60-minute anneal at the same temperature; recrystallization is complete and grain growth marked. Grains in the latter instance are about twice as large as in the former. Enlarged grains were found in the same microsection as Fig. 47 was taken from, at a point about midway between the

FIG. 51.

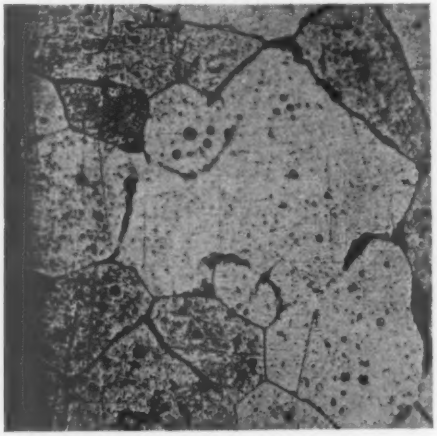


Centre of microsection; after four-hour exposure at 595° C.; ×50.

edge and the centre; thus Fig. 49 shows these enlarged grains resulting in part of a section after a 10-minute exposure at 595°C. Fig. 47 shows the almost completely recrystallized structure in the same section where the strain was less. Fig. 50 shows very well the enlarged and small grains resulting from differential strain and a subsequent exposure of 60 minutes at 595°C.; the relatively large space bounded by the small grains at the right-hand side of the micrograph and by the slightly darkened portion of a grain at the left-hand side is a single grain.

Fig. 51 is a micrograph of a sample exposed for four hours at 595°C.; beautiful allotriomorphic grains have resulted from this treatment, and they are larger than those shown in Fig. 48, where the anneal was for 60 minutes at the same temperature. The grain size of the former was 26 per sq. mm., and of the latter 34 per sq. mm. Enlarged grains were found at the edge of the same microsection where the strain had been greatest, as is shown in Fig. 52. The micrographs shown have indicated three zones, with as many sizes of grains in a section: *viz.*, (1) a zone of least strain where recrystallization proceeds slowest; (2) a zone of greater strain where recrystallization proceeds fastest;

FIG. 52.



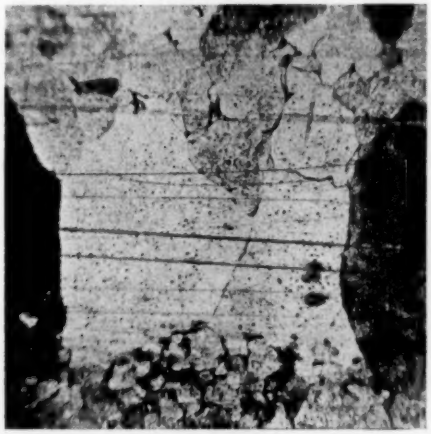
Enlarged grains at edge of microsection; after four-hour exposure at 595° C.; × 50.

and (3) a zone of greatest strain where recrystallization is slower than in (2), but faster than in (1). Zone 1 is located farthest from the edge where the shear blade passed; zone 2 is approximately midway between zone 1 (at the centre of the section) and the edge; and zone 3 is right at the edge and extending for about one-sixteenth of an inch inwards towards the centre. Still more conclusive evidence, if possible, showing the deformation zones, is the micrograph in Fig. 53, unfortunately scratched, which shows three sizes of grains from edge to centre; the grains of fairly large size, in the upper third of the micrograph, represent the structure of the metal at the edge; the considerably enlarged

grains, in the centre third, represent a portion of the metal a little farther away from the edge and towards the centre; while the relatively small grains, in the lower part of the micrograph, represent the average structure of the metal in the centre of the section. In the foregoing, the sample was exposed for four hours at 595°C.

Considering these facts and the micrographic evidence, it follows that the grains at the edge have not grown to the size of the grains immediately adjacent for one or a combination of the following reasons:

FIG. 53.



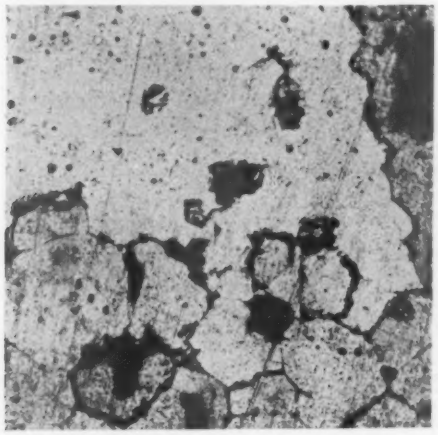
Three sizes of grains in section; after four-hour exposure at 595° C.; × 20.

(1) Metal was not available on the edge side of the microsection to allow grain growth by migration outwards;
(2) The largest grains grew in both directions, toward centre and edge, at the expense of the adjoining grains; and
(3) The largest grains were located at the point of critical strain for the temperature employed, and hence the largest grains resulted there.

Under the conditions of these experiments, it was invariably observed that wherever there had been differential grain growth, those grains at the edge were smaller than ones a little farther in from the edge towards the centre of the microsection, and yet

larger than those in the centre. In other words, those grains at a point which has been strained intermediately between two extremes grew to be the largest. Figs. 55 and 56 are micrographs showing the alteration in internal structure accompanying annealing for 10 minutes at 540°C., while in Figs. 57 and 58 are shown the results of a 10-minute exposure at 485°C.; in both anneals, it will be seen that differential grain growth has ensued, although the metal in the centre of the microsections is apparently not fully recrystallized in either case. At the point of critical strain, however, enlarged grains have developed bordered by small grains approximately equiaxed. Although the amount of

FIG. 54.



Juncture of large and small grains; after four-hour exposure at 595° C.; × 50.

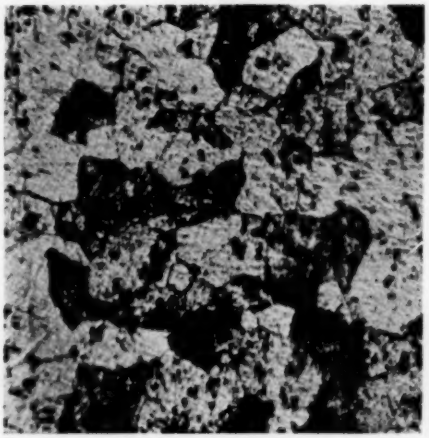
strain given to the metal by the cold shearing is indefinite, *i.e.*, it could not be measured in units, the effects of temperature on such strain are recorded, and the exaggerated growth following such strain on annealing is shown beyond any doubt.

VII. SLIP BANDS IN ALUMINUM.

When substantially pure aluminum, or one of its ductile alloys, is strained, slip bands are formed, but no twinning as the result of direct mechanical strain has so far been observed. The origin of slip bands arises in the sliding or slip in the crystals of a ductile metal when plastic deformation acts, and the slip bands make themselves evident as fine, straight or curved, lines on the

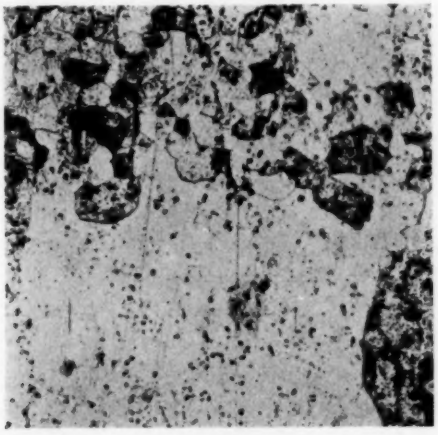
faces of the individual crystals. They may be very conveniently developed by polishing and etching a sample of metal and then sub-

FIG. 55.



Centre of microsection; after 10-minute exposure at 540° C.; × 100.

FIG. 56.

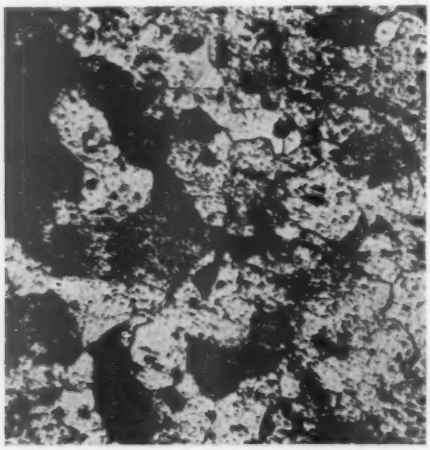


Juncture of large and small grains; after 10-minute exposure at 540° C.; × 100.

jecting it to stress exceeding the elastic limit. Slip bands in aluminum and two of its alloys have been developed by direct compres-

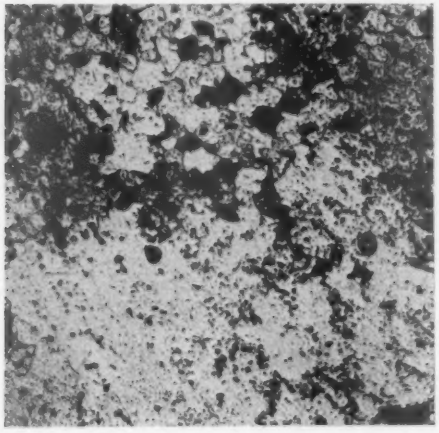
sion of previously polished and etched samples; micrographs are shown in Figs. 59 to 64. Under the microscope, a slip band is

FIG. 57.



Centre of microsection; after 10-minute exposure at 485° C.; × 100.

FIG. 58.

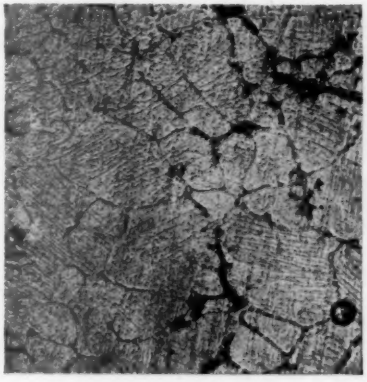


Juncture of large and small grains; after 10-minute exposure at 485° C.; × 50.

seen black under vertical illumination, since the surface is not horizontal and does not reflect the light vertically back into the

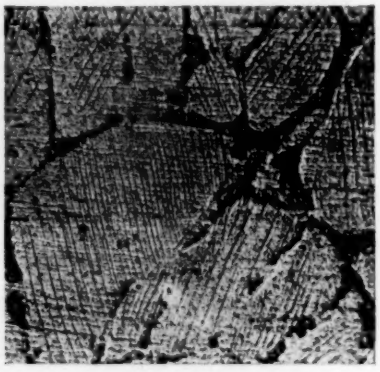
tube of the microscope. No comprehensive discussion of the nature of slip bands is contemplated, but the main facts may be indicated. Their crystallographic direction, in certain instances, tends to show that they represent slip along crystallographic planes; Osmond, however, interpreted only straight slip bands as representing crystalline motion. Slip bands are to be distinguished from Neumann bands, which are the outcrops of mechanically twinned lamellæ set up in ferrite and some other metals, *e.g.*, bismuth, by deformation. What Howe (26) calls X bands are rough striæ found on polishing and etching iron which has undergone severe plastic deformation; when ferrite is deformed so as to produce slip bands, and then repolished so as

FIG. 59.



Slip bands in 1.65 per cent. Mn–Al alloy; etched with NaOH; × 125.

FIG. 60.



Slip bands in 1.65 per cent. Mn–Al alloy; etched with NaOH; × 250.

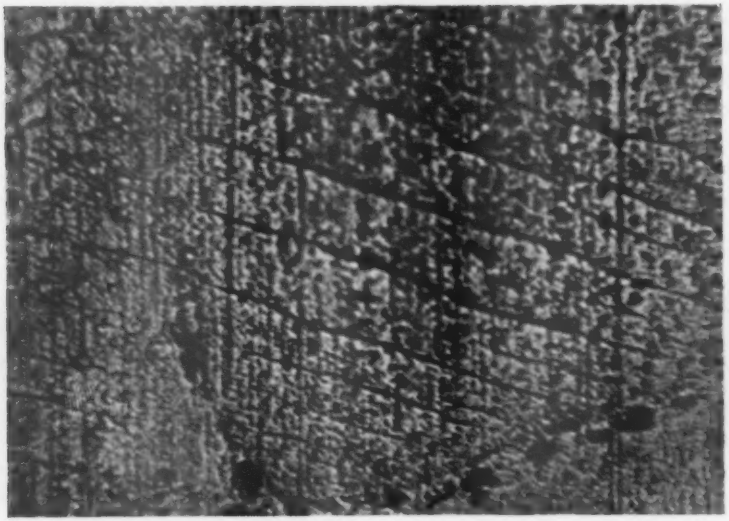
to efface the slip bands and then etched, bands may appear, which are called X bands. Their nature is unknown.

Figs. 59 to 61 show slip bands in the aluminum alloy containing 1.65 per cent. Mn., at various magnifications; the bands are uni-directional in any given grain. Figs. 62 and 63 show these bands in an impure aluminum sample, where two sets of bands within individual grains are found, crossing each other at an angle of approximately 65°. Bands in Fig. 64 were developed in substantially pure aluminum by severe compression; the surface of the sample was much roughened and difficult to photograph.

VIII. POLISHING AND ETCHING ALUMINUM.

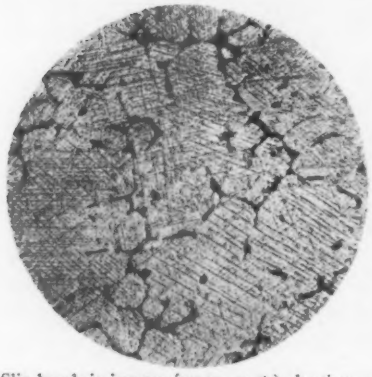
Aluminum is a difficult metal to satisfactorily polish and etch (55,60), and even when the usual precautions are observed it

FIG. 61.



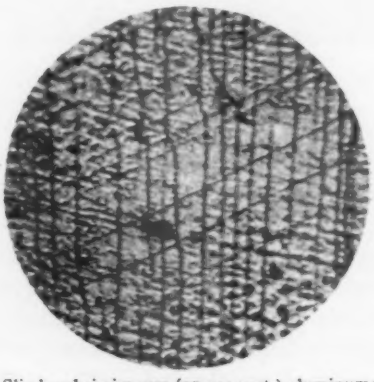
Slip bands in 1.65 per cent. Mn-Al alloy; etched with NaOH; × 1000.

FIG. 62.



Slip bands in impure (97 per cent.) aluminum; etched with NaOH; × 125.

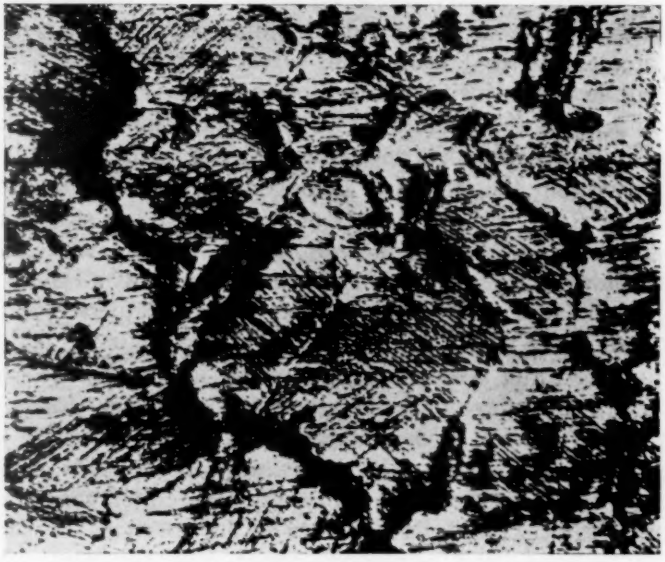
FIG. 63.



Slip bands in impure (97 per cent.) aluminum; etched with NaOH; × 1000.

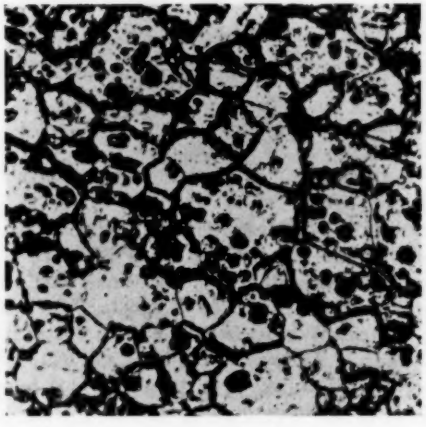
does not at times yield satisfactory microsections. One difficulty lies in its softness and ease of amorphization under polishing press-

FIG. 64.



Slip bands in substantially pure cast aluminum; × 200.

FIG. 65.



Etching pits in annealed aluminum; × 200.

ure, and another is the choice of an etching reagent. There have been elsewhere (55,59) described methods for the preparation of aluminum microsections, and here there will only be confirmed the statement which I have made before; *viz.*, that hydrofluoric acid will, in the majority of cases, be found the most satisfactory etching reagent for aluminum. Until some other reagent is developed, and hydrofluoric acid is not all that is desired, this will have to remain the standard etching agent for aluminum; for aluminum alloys, other reagents are at times more satisfactory. At best, aluminum is very difficult to etch (61). In the micrographs shown in the present paper, the etching was all done with hydrofluoric acid, usually about 8 per cent. in aqueous solution, unless otherwise noted. In etching with hydrofluoric acid, it is best to follow the attack with immersion in concentrated nitric acid, in order to remove the black deposit which forms and brighten the sample. When using sodium hydroxide, the usual strength employed is a 10 per cent. aqueous solution, and the etching attack is followed by immersion in either concentrated chromic or nitric acid; lately, very dilute solutions of sodium hydroxide have been employed—about 0.10 per cent. With hydrofluoric acid, aluminum tends to develop etching pits, particularly in annealed samples; etching pits, in a sample of drawn and annealed aluminum, are shown in Fig. 65.

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A Self-Adjusting Thrust Bearing. H. G. REIST. (*General Electric Review*, vol. 21, No. 7, July, 1918.)—Thurst bearings for supporting the heavy loads of water-wheels and electric generators driven by them are now very widely used. The difficulties in the fitting and use of plate bearings are much aggravated, as the load is increased on account of the large over-all dimensions of the supporting plate. It is true that the surface can be fitted quite accurately by machine, but there have been cases where the surfaces have been turned slightly conical, with the result that they bore hard on the inner or outer edge. The deflection of the supporting collar in the shaft may allow the runner to be slightly dished, or there may be a deflection of the supporting surface, thereby dishing the babbitted seat or causing one side to become lower than the other. The self-adjusting spherical seat, provided to correct some of these difficulties, is of doubtful value on large bearings on account of the great frictional resistance which must be overcome to make it shift.

Thrust-bearing surfaces are usually scraped to each other, or to a surface plate, to avoid dangerously high spots; but since the oil-film is of the order of two ten-thousandths to three ten-thousandths of an inch in thickness, the difference in level must be smaller than these values. This work must usually be done without load, and no matter how carefully it is done, when the bearing is loaded the parts will not fit each other because of deflection.

A careful study of the above difficulties led to the design of a flexible bearing surface pressed against the runner by springs. It seemed that this would prevent the possibility of undue pressure at any point and compel each element of the surface to carry its share of the load. On trial this solution proved satisfactory.

In a typical design for vertical shaft machines, the bearing consists of a runner of a special grade of cast iron resting on a thin steel ring which has a babbitted surface. The babbitted stationary ring, in turn, rests on short helical springs and is held against rotation by dowel pins. A saw-cut through one side eliminates any tendency of the ring to "dish" with a change in temperature. The springs ordinarily used are of one-half inch round wire, with an outside diameter of two inches, and a free length of one and one-half inches. Under load the springs close about one-sixteenth of an inch, and the total pressure is well distributed. By this means it is possible to avoid excessive pressures at any point. Thus it is safe to run with much higher average pressure than when there is no definite limit to the pressure which may occur over a small area.

A TRIBUTE.
SAMUEL PIERPONT LANGLEY: PIONEER IN PRACTICAL AVIATION.*

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It may be safely assumed, I think, that mankind from its earliest period of self-consciousness had aspirations of flying. In primitive times birds were more abundant and varied than at present, at least in civilized countries, and the ease and grace of their flight must have profoundly impressed the rudest races. The legend of Icarus and his waxen wings is one of the expressions of this feeling. Among the world-wide and very ancient witchcraft legends we find the gift of flying a usual feature. In the later phases of these superstitions, especially as they appear in English-speaking nations, the highly unromantic method of broomstick flight is eminently characteristic.

Notwithstanding all aspirations, no practical method of flight by human beings can be demonstrated until 1783, when the brothers Montogolfier sent up a hot-air balloon. Hydrogen gas was soon after substituted for air, and the balloon in substantially its present form was produced. The standard form of balloon, however, does not fly in the full sense of the word; it simply floats in the air, subject to the currents thereof. Its modification, the dirigible, which has acquired such prominence in recent years, especially in the form known as the Zeppelin, has solved some of the problems of flight, but it is an expensive, complicated and untrustworthy form, and has very limited practical application.

All creatures that fly are heavier than air, and this leads to the view that it will be by the method they use, namely, reaction upon the air as a material substance, that true flight will be obtained.

This was Langley's view, and it is to his honor that he insisted on this principle, and pointed the way, both in theory and practice, to its accomplishment. It is the purpose of this paper to summarize his main work, and to present his claims to the

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gratitude and admiration of the American people. The history of the later years of his life, when he was approaching the solution of the problem, in fact, had attained it, is one of the tragedies of science, and a painful reminder of the gap that still exists between the true scientist and the mass of the community, even in highly civilized lands.

It would, however, be inaccurate to claim for Langley, absolute priority for the idea that a heavier-than-air machine can be made to fly. To think of an invention is a simple mental effort, and there are few of the great inventions or discoveries of the modern time that cannot be found foreshadowed in the records of the past. A Greek poet describes in set terms the invention of submarine warfare, when Scyllus and his daughter, expert swimmers, dived at the sides of Xerxes' ships, cut the mooring cables, and thus caused many ships to drift to their destruction.

About the time of the discovery of America, that remarkable and versatile genius, Leonardo Da Vinci, wrote an essay on the flight of birds, and referred to the possibility of human flight. I have not been able to consult the original essay, but notes thereon, by Da Vinci, have been translated,[1] and from this text I make a few selections.

"I have divided the *Treatise on Birds* into four books: of "which the first treats of their flight by beating their wings; the "second of flight without beating the wings, and with the help of "the wind; the third of flight in general, such as that of birds, bats, "fishes, animals and insects; the last of the mechanism of this "movement." * * * * *

"Remember that your bird should have no other model "than that of the bat, because its membranes serve as armor, or "rather as a means of binding together the pieces of its armor, "that is the framework of the wings. * * * * The bat is "aided by the membrane which binds the whole together, and is "not penetrated by the air."

"Dissect the bat, study it carefully and on this model con-"struct the machine.

"The bird I have described ought to be able by the help of "the wind to rise to a great height, and this will prove to be its

[1] Leonardo Da Vinci's Note Books. Translated by Edward McCurdy, A.M. London, Duckworth and Company, 1906.

"safety; since even if all the above-mentioned revolutions were "to befall it, it would still have time to regain its equilibrium; pro- "vided that its various parts have a great power of resistance, so "that they can safely withstand the fury and violence of the "descent, by the aid of the defences which I have mentioned; and "the joints should be made of strong tanned hide, and sewn with "cords of very strong raw silk. And let no one encumber himself "with iron bands, for these are soon broken at the joints, or else "they become worn out, and consequently it is well not to encum- "ber one's self with them."

It will be seen from these quotations that Da Vinci's plan was to equip a man with wings to be operated by his muscles, probably those of both legs and arms, for in another note he states that the muscles of the legs are much more powerful than the ordinary work done by them requires. He did not contemplate the use of machinery. It must be borne in mind that in that day, no powerful, portable prime-mover was known.

Attempts have been made to credit Da Vinci with the anticipation of the modern aeroplane, but there is nothing in his essay which can justify this claim. He made a study of the flight of birds, but his inferences were not correct in some important respects, and while we may give him credit for scientific method, it is apparent that he "thought of" rather than "thought out" the problem of human flight. Langley does not appear to have been acquainted with Da Vinci's work, at least it is not quoted in any of his writings that I have consulted, and in the article in the ninth edition of the *Encyclopedia Britannica*, which is given among his references, there is no mention of Da Vinci's investigations, but these are briefly noted in the eleventh edition (article on "Flight and Flying").

Claims have been made for many experimenters and investigators, as having made flights with small machines, but definite data have rarely been furnished, and it is probable that Langley is justified in his claim that until the experiments in May, 1896—to be later described—no true flight of a heavier-than-air machine had been made.

Machines based on the principle that Da Vinci discussed have been built and operated by several investigators. These have been mostly "gliders," enabling the person to make a slow, inclined descent from a high point, but not conferring the power

of rising from the ground or alighting at a given place at a considerable distance from the starting point. A glider of this type was constructed by Otto Lilienthal, and operated many times in the year 1896. He was killed by the upsetting of his machine in a gust. Percy Pilcher made many such flights in 1899, but also lost his life in an accident. Octave Chanute, however, made over a thousand flights without injury to himself. These operators sometimes made their flight by running the machine, or having it pulled, against the wind and thus rising from the ground much the same way as a kite is flown. It is obvious, however, that these machines do not solve the problem of flying in its important practical applications. It is also obvious that modern flying machines, whether the dirigible balloon or the aeroplane, do not act wholly on the principles of flight by the bird or insect.

It is interesting to note that in animals the ratio of wing area to weight diminishes as the weight increases. Thus, according to the *Encyclopedia Britannica,* the wing-area of the dragon-fly is, in proportion to its weight, nearly twenty-five times that of the pigeon.

Langley began his investigations in 1887, at the Allegheny Observatory. At that time he was not aware that any other investigator had accomplished anything along the lines that he was working, but he subsequently found out that A. Pénaud, an ingenious French mechanician, had made in 1872, a machine about twenty inches long resembling some of the simpler modern aeroplanes, using twisted rubber as a motive power. He had described this in a journal called "L'Aéronaute." No copy of this journal is accessible to me, but the details of Pénaud's machine with pictures are given in the memoir quoted below. Pénaud stated that he had obtained a flight of 60 meters during 13 seconds. Langley was never able to obtain such results, but states that twisted rubber has a very high potential, being much more efficient than any steel spring he tried.

From the start Langley proceeded in a truly scientific manner, studying the mathematics and physics of the problem, preliminary to construction of apparatus. His results are set forth in two publications, "The Internal Work of the Wind" and "Experiments in Aerodynamics." He discovered that the law laid down by Newton, and accepted by most mathematicians and

physicists, namely, that atmospheric resistance to inclined surfaces is proportionate to the square of the sine of the angle of inclination, is not founded in fact, the resistance being really proportionate to the angle directly. The interesting story of the invention of the practical aeroplane is to be found in the ponderous quarto of over 300 pages, entitled "The Langley Memoir on Mechanical Flight," published by the Smithsonian Institution, and consisting of two papers, one mostly by Langley himself, the other by his faithful and efficient assistant, Charles M. Manly. It is from this publication that I have drawn most of the material for this essay.

Notwithstanding that the problem of flight had engaged human attention for many centuries, and had attracted all classes of persons, ranging from such a profound genius as Da Vinci to mere cranks and dreamers, yet when Langley took up the matter there were but few data available, and there was almost no one disposed to give him encouragement, tangible or sentimental. Distinguished scientists deprecated investigations into the subject. As late as 1900 a prominent astronomer and mathematician declared that it would be impossible to construct a machine capable of sustaining the weight of the largest known birds, not knowing that two of Langley's machines had already accomplished more than this. "The truly blind are those who will not see."

After several years' assiduous labor, he was able to announce that it is possible to give such velocity to inclined surfaces that bodies indefinitely heavier than air could be driven through it with great velocity. As a concrete instance, he states that a plane surface, 76.2 centimeters by 12.2 centimeters (about 1 sq. foot) weighing 500 grams, could be driven through air in absolutely horizontal flight at the rate of 20 meters per second with 0.01 horse-power. This is equivalent to a weight of 200 lbs. driven through air by 1 h.p. at 40 miles per hour.

Following up this conclusion, a number of machines were constructed and tried out, some of them, of course, quite small, others of considerable size. For all the machines he made Langley coined the word "Aerodrome," from two Greek words meaning "air runner." This word is now often used as the name for the shed in which the flying machine is stored.

In passing from very small machines in which twisted rub-

ber or steel springs can be used—which are mere toys—to large machines which can make reasonably long flights, the question of motor became of great importance. Questions of stability, both lateral and longitudinal, also required answer. I will not enter into a consideration of stability problems. They were most carefully investigated by Langley, and involved mathematical as well as mechanical methods. It is now well known that the stability of aeroplanes has been satisfactorily attained.

When Langley began his experiments, the only motor that seemed to offer practical application was the steam-engine. This had been for a long while the only one applicable to a moving object, as is indicated by its extensive use in both land and water transportation. The steam-engine is heavy, and also requires fuel and water, so that the total weight is considerable. In the ordinary uses of it in land transportation this is not a very serious matter, for the locomotive draws best when it presses strongly on the rails, and even in water transportation, the weight of engine, fuel and water are probably of less importance than the space they occupy. Langley, in 1891, canvassed the portable motors then known. These were, in addition to steam, compressed air, liquid carbon dioxid, electric batteries, gunpowder, and the internal combustion engine. The last-named, which is now the only motor used in flying machines, was at that time but little developed, and was rejected, as were all the others except the steam-engine. The requirements were that the apparatus should be light, capable of developing steam rapidly and at considerable pressure, and using a fuel of high heating efficiency. Water-tube boilers were alone suitable, alcohol or gasoline as the fuel. Oscillating engines were used at first. Many experiments were made with boilers and with burners, and much difficulty was experienced in getting and maintaining sufficient pressure. Langley's accounts of the failures and disappointments make painful reading, but space does not permit a summary of these matters, especially as the steam-engine has ceased to be important in the field with which we are now concerned.

After many months of weary working, it was finally thought to be possible to secure a flight in the open air, and preparations were made for this. The story of the failures, disasters and disappointments that preceded the actual flight—told with much vividness in the "Memoir"—is a striking instance of the will-

power and self-reliance of the inventor, and of his possessing to a high degree that characteristic of genius, "the infinite capacity of taking trouble."

After succeeding in the construction of a power-driven flying machine, two problems were presented in connection with open-air trials: a suitable locality and a method of launching. It was decided that it would be safest to launch the machine over water, as in case of a fall it would be not seriously damaged and be readily recovered. It was, of course, also advisable that the location should not be far from Washington, at which place the construction was being carried on, and should not be in a populated district. The spot chosen was a small island in the Potomac River, about thirty miles below Washington.

For launching the machine, a sort of house-boat was built by putting a frame room on a scow, and on the roof of this a horizontal track with releasing apparatus. The room served for storing the machine and was fitted with apparatus for repair work.

In the latter part of 1893, an aerodrome, designated as No. 4, was taken to the trial-ground, but though eight trips were made for trials, none was successful, and the year closed without any demonstration of the capacity of the machine. The year 1894 also passed without any successful flight, although a few short movements had been secured, and the machines seemed to be less erratic and the power was shown to be sufficient for the work. Little better results were obtained during 1895, but much information as to the defects of construction were obtained, so that with the opening of the following year, the problem was much nearer solution, in fact, was solved.

In the early part of 1896, two aerodromes, 5 and 6, were available, and on May 6 of that year, Langley with A. Graham Bell and several assistants were at the trial-ground. The wind was so high during the morning that no attempt at flight was made, but at 1 P.M. it had become much less active, and at 1.10, aerodrome No. 6 was launched, but owing to some entanglement with the launching apparatus, it settled directly into the water. Aerodrome 5 was then tried. At 3.05 it was launched with a steam pressure of 150 lbs., and started directly into the gentle breeze that was blowing.

The height of the launching track above the water was about

twenty feet; the machine, first descended about three feet, but immediately began to rise until the midrib made an angle of about 10 degrees with the horizontal, and maintained this mostly through the entire flight. After leaving the boat, it circled to the right and moved with great steadiness, making a spiral path

FIG. 1.

Instantaneous photograph of aerodrome in flight at Quantico, Potomac River, May 6, 1896.
"Langley Memoir on Mechanical Flight." Plate 21.

of two complete turns and part of a third. During the first two turns the apparatus was constantly ascending, and at the end of the second turn, had reached a height, estimated at over 75 feet. The power then began to give out and the machine slowly descended, striking the water in approximation to a "nose-dive," having been in the air 80 seconds and travelled about 3,300 feet,

which would mean a rate of about 20 miles per hour. The machine was recovered at once, and being found not injured, a second trial was made, with somewhat similar result, making three turns at a height of about sixty feet, during 91 seconds, over a path estimated as carefully as possible at 2,300 feet. Several photographs were taken during these flights.

These flights, of course, meant much to the patient inventor and his friends. For the first time in the history of the world a heavier-than-air machine had actually flown through the air and preserved its equilibrium without the aid of a guiding intelligence. Moreover, a second trial had been made, thus showing that the first was no mere accident.

It seems somewhat curious that these striking results were not immediately followed up. No explanation of the suspension of the experiments is given in the "Memoir," except to say that the inventor left for Europe, intending to be away until fall. Instructions were given to the mechanicians to remedy certain small defects in the machines.

On November 27, a trial was made of aerodome 6, but owing to the breaking of a pin, the trial was a failure. In the afternoon of the next day, a successful flight was made, the machine going in a curved path of about three-quarters of a mile in 105 seconds, a rate of about thirty miles per hour. *"Finis coronat opus."*

Obviously the success of the aerodromes led to the thought of the construction of a man-carrying machine. Langley hesitated on account of the many duties in connection with his official relations with the Smithsonian Institution, yet the longing to take the final step was too attractive to his scientific mind and soon took possession of him. Ten years had been passed in laborious experiment, full of disheartening difficulties, and he thoroughly realized that the construction of a machine large enough to carry a man would be a mighty labor, but his spirit was no flickering flame like that of light straw, but determined and devoted to the object of science—the discovery of truth.

In undertaking the construction of a large aerodrome, Langley was much influenced by President McKinley, who had become impressed with the value of the instrument in war. It will not be necessary to set forth here the official procedures which led up to the work, but merely to state that in the latter part of 1898,

an appropriation of $50,000 was made for the purpose through the Board of Ordnance and Fortification.

Langley had always recognized that one of the most important problems in a flying machine is the motor, which should be light, powerful and capable of maintaining its action for a long time on a small volume of fuel and other supplies (such as water). The internal-combustion engine, then coming into notice, was obviously the most promising form, but as he was not familiar with this apparatus, he deemed it proper to delay definite action until a satisfactory engine could be secured. After much searching, a contract was placed on December 28, 1898, for a 12 h.p. engine to weigh not more than 100 lbs., and the construction of an aerodrome for use with this engine was at once begun. Notwithstanding the amount of research that had been given to the mathematics and physics of flight of heavier-than-air machines, it was felt that the new problem required much more investigation and research, and of course, a new element entered into it, namely that of preventing the injury or death of the operator.

The great complexity of the problem induced Langley to seek the services of a mechanical engineer, and on the recommendation of Professor Thurston, Mr. Charles M. Manly was appointed, and proved to be a most efficient and faithful worker. It was hoped that the engine could be obtained and the frame-work of the new aerodrome completed by the early part of 1899, but this was not to be. The engine builder though he exerted himself to the utmost and, indeed, lost much money in his effort, was not able to produce an engine which would give anything like the desired h.p. within the allowable weight. Another series of disheartening failures and disasters followed. As a preliminary, an aerodrome one-quarter size of the proposed man-carrying one was constructed and trial flights made with success, but this small machine could not, of course, carry an operator. In addition to the problem of the construction of the large machine, a new apparatus for launching was devised and a new location, about forty miles below Washington on the Potomac was selected. It became necessary here to have a tug-boat and housing for the workmen, who could not come and go from Washington every day.

Nowadays, when aeroplanes are among familiar objects and almost everyone has seen them start and land, it seems that

a serious mistake was made in the elaborate launching apparatus, and in the principle of launching over water, but it is easy to be wise after the event, and we must always keep in mind that Langley was working in a field in which there was no definite guidance, save his own studies and experiments.

The engine-builder having finally given up the problem, efforts were made to get some European builder to manufacture the apparatus, Europe being, it was thought at that time, ahead of America in the application of the internal combustion motor. No one could be found willing to undertake the contract. Under these circumstances, Mr. Manly undertook the work. He obtained the parts of the engine which the American builder had made and in the latter part of 1900 began his work. He was able in September of that year, to construct an engine weighing 108 pounds which gave on the Prony brake, 18.5 h.p. at 750 r.p.m. The cylinders were, however, without water-jackets, being cooled with wet cloths, which of course would permit only short runs.

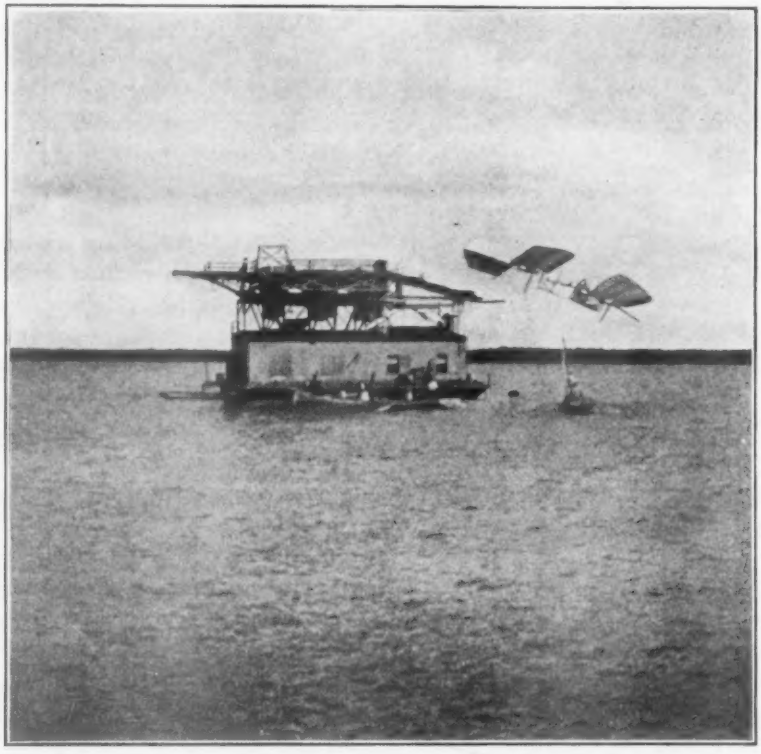
The details of the development of the engine, of the difficulties with sparking apparatus, carburetors, pistons, packing, lubrication and all the other vexations that go to make up what are collectively known as "engine troubles" are described vividly and fully in the "Memoir," but space does not permit of even a brief summary here. Not the least of the troubles in the history of the affair was the weather, which was very often exceedingly unfavorable.

Mr. Manly volunteered to be the operator for the first trip of the aerodrome. His chief consented to this, though with much reluctance. Every possible precaution was taken to prevent serious accident, and on October 7, 1903, about sixteen years after the work had begun at the Allegheny observatory, the machine was launched with Manly in the aviator's chair. It was a little after noon that the machine glided down the launching track. The operator soon felt the sensation of being free in the air, when he noted that he was plunging downward at a very sharp angle, and instinctively grasped the wheel which controlled the Pénaud tail, intending to throw it up so as to depress the rear, but the effort failed, the machine crashed into the water and it was with some difficulty that the operator was saved from drowning. The machine was recovered from the water and certain slight defects discovered as the cause of the mishap. Arrangements were made

to remedy these and the party returned to Washington, after giving out a brief statement to the press. Fortunately, an excellent photograph had been secured just as the machine left the launching platform, and also another taken close to the wings, from which certain important facts can be easily established.

Examination showed that the machine was not seriously

FIG. 2.



Flight of large aerodrome, October 7, 1903. "Langley Memoir on Mechanical Flight." Plate 95.

injured and it was decided to make another attempt, but for convenience a spot much nearer to Washington was chosen. On account of the lateness of the season, favorable weather was unusual, and it was December 8 before conditions were satisfactory. Some delay occurred in getting the machine taken to the place of trial, and darkness was setting in and the wind had become strong and gusty. Nevertheless, Manly took his station at the wheel, and the

machine was launched, but something happened that has never been clearly determined. The machine shot upward and then fell into the water, entangling the pilot, who again narrowly escaped drowning. Owing to the darkness the official photographer got no pictures, as his shutters were set to too high speed, but a representative of the *Washington Star* secured a small photograph, which on enlargement showed some points of importance, principally that the accident was due to the rudder becoming entangled in the launching track, owing to the breakage of some part of the mechanism by which it was connected to the main frame.

The situation became very distressing. The inventor felt that he could not ask for further funds from the Smithsonian Institution, and the Board of Ordnance and Fortification having been severely criticized on the floor of Congress for its original allotment for the work, it was deemed inexpedient to ask for further aid, as it might incur a curtailment of the funds placed at the disposal of the Board.

In 1904, Manly made efforts to secure assistance from wealthy Americans, but all whom he approached declined to aid unless arrangement would be made for later commercialization. Langley had years before tempting offers of this character, but had always declined and he again declined to accept these conditions. In 1907 he died. Had he been spared a few years he would have seen all his hopes realized as the sequel shows.

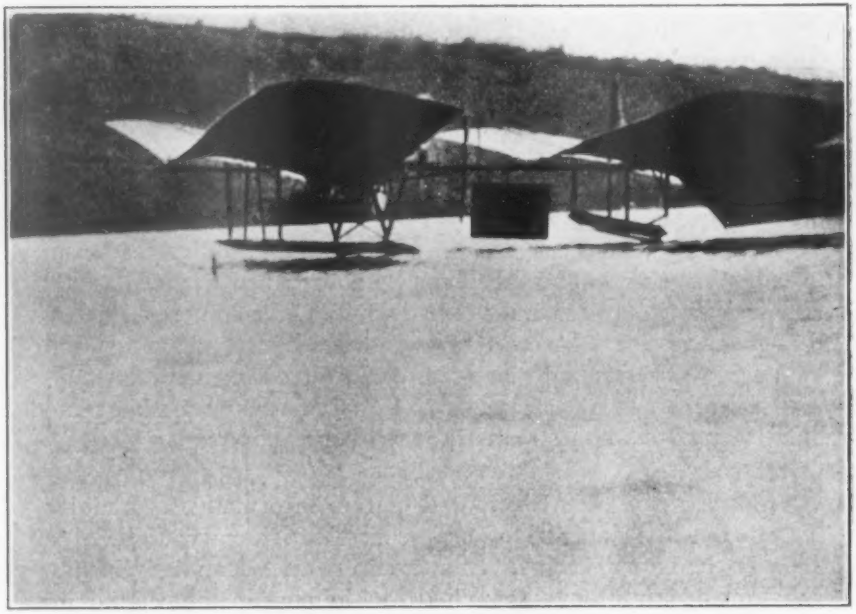
THE SEQUEL.[2]

May 6 is celebrated in Washington, informally, as Langley Day, being the anniversary of the first satisfactory flight of a heavier-than-air machine. In March, 1914, Glenn H. Curtiss, aviator and inventor, was invited to take part in the ceremonies on the next occasion. He replied: "I would like to put the Langley Aerodrome itself in the air." Secretary Walcott, of the Smithsonian Institution, at once granted the request, and in April the machine was taken to the Curtiss plant on Lake Keuka, Hammondsport, N. Y. It was overhauled but not materially changed, except to put hydroplane floats on it. On May 28, 1914, two months before the great war broke out, and eighteen years after the successful flight of the first aerodrome, the craft of 1903 was lifted into the water with Curtiss at the wheel, and many eager

[2] For most of the data of this paragraph I am indebted to an article by Dr. A. F. Zahm, in *Ann. Rep. Smithson. Inst.* for 1914.

camera men waiting with loaded weapons. Pointed somewhat across the wind, the machine automatically headed into it, rose in level poise, soared steadily for 150 feet and landed softly in the water. After a few more flights, the engine and propellers were replaced by an 80 h.p. Curtiss motor, and direct-connected tractor propellers. In the absence of Mr. Curtiss, a pupil of his school, Mr. Doherty, took the wheel. Beginning Sept. 17, a number of flights were made, which demonstrated that the general principles

FIG 3.



Langley aerodrome rising from water, with Glenn H. Curtiss as pilot, June 2, 1914, Lake Keuka, N. Y.
A. F. Zahm, Smithsonian Reports, 1914.

of Langley's construction were perfectly sound, and to him must be given the credit of being the pioneer in practical aviation, and of having, by his devotion and persistence, helped to bring into a field of scientific inquiry what had been previously almost entirely in the possession of visionaries or charlatans. In this connection we must not overlook the services of Manly, to whom is due largely the construction of a satisfactory gasoline engine, then first used in an aeroplane, and who twice risked his life in trials of the large machine.

The following paragraphs are copied verbatim from the article indicated in the footnote on page 61:

"Dr. Langley's aerotechnic work may be briefly summarized as follows:

"1. His aerodynamic experiments, some published and some as yet unpublished, were complete enough to form a basis for practical pioneer aviation.

"2. He built and launched, in 1896, the first steam model aeroplane capable of prolonged free flight and possessing good inherent stability.

"3. He built the first internal-combustion motor suitable for a practical man-carrying aeroplane.

"4. He developed and successfully launched the first gasoline model aeroplane capable of sustained free flight.

"5. He developed and built the first man-carrying aeroplane capable of sustained free flight."

Gas Masks. E. C. PORTER. (*American Machinist,* vol. 49, No. 20, p. 911, November 14, 1918.)—German poison gas has been found harmless against gas masks worn by the United States troops in France. Field tests show that these masks afford twenty times more protection than German masks, and there is not a single case on record of an American soldier falling victim to a German gas attack when wearing the masks manufactured in the United States. This fact has been so thoroughly established by repeated experiences that military authorities place the blame for gas poisoning on the carelessness of the victim. Many American Army officers believe that in most cases the men who get gassed should be courtmartialed, not decorated. Every American soldier who goes to France is a gas-mask expert. He has been trained to adjust his "land life preserver" with almost incredible speed. The mask is put on with five motions of the arm and hands. Although a gas mask is a very uncomfortable article to wear the first few times, the soldier soon becomes accustomed to this handicap on the natural way of breathing. It fits over the head like a baseball catcher's mask. A nose clip closes the nostrils and insures breathing through the mouth by a tube connected with a canister filled with chemicals. The exhaled breath leaves through a flutter valve near the chin. Air cannot reach the mouth except by passing through the chemicals in the canister, and exhaustive experiments show that these chemicals never fail to extract the poison.

Better Frequency Control. H. E. WARREN. (*General Electric Review*, vol. 21, No. 11, p. 816, November, 1918.)—As is well known, the ordinary method of measuring frequency is by means of a meter which indicates upon a scale the value at any instant. Such a meter, under observation by a switchboard operator, serves to establish the speed of the turbines which is regulated through the electric speed controllers of the governors manipulated from the switchboard. This common method of regulation has certain faults which hitherto have not been emphasized because there has been no better way of accomplishing the regulation. An improved method of maintaining frequency, which has been in actual use during the past two years by a few of the largest power companies in New England and New York City, differs radically from the conventional plan. No frequency meter of the ordinary type is required. Instead, a device, which conveniently and accurately compares the integrated alterations with elapsed time, serves as a guide to the operator for adjusting the speed of the turbines. The device is comparatively insensitive to the instantaneous value of the frequency, but shows its average value with the very greatest precision.

The instrument itself, which is known as the Warren master clock, consists of a precise complete pendulum clock with two dials, placed one above the other. The lower one, which is of no particular importance for the purpose, serves merely to indicate the time in the conventional manner. The upper dial, of larger diameter, has a hand which revolves once in five minutes. Mounted upon the upper five-minute dial of this clock is an additional hand which is gold-colored to distinguish it from the black clock hand. This gold hand is wholly independent of the clock movement and is driven through gearing by a small self-starting synchronous motor. This motor is connected permanently through any convenient potential transformer to the alternating current system. The gear-ratio between the gold hand and the motor is such that at normal frequency, for example 60 cycles, the hand will revolve once in precisely five minutes. Incidentally the synchronous motor keeps the pendulum clock movement constantly wound at uniform tension.

After the clock has been started and regulated, the gold and black hands on the five-minute dial are set over each other, and the operators are instructed to adjust the speed control switches of the turbines occasionally, if they observe any tendency of the gold hand to gain or lose with respect to the black hand. The clock gives a true indication of the average value of the speed. It does not respond visibly to momentary fluctuations and serves, therefore, to establish a correct base line for the frequency.

A NEW THEORY OF PLATE SPRINGS.*†

BY

DAVID LANDAU and PERCY H. PARR.

Having completed our study of the reactions and deflections of springs with square pointed leaves, we pass on to the study of the

No. 2 or Trapezoidal (Trap') Leaf Point.

This type of point is shown on a larger scale in Fig. 18, on which are also given the symbols which will be used in the analysis. The end of the leaf is of uniform thickness with the central portion, but it is cut off to a straight taper in the plane of the width.

We shall use I_0 to indicate the moment of inertia of the untapered portion of the plate, for this and for all other types of tapered points.

In order to determine the deflections of leaves with the No. 2 point we have:

First: From $X = 0$ to $X = l - a$.

For this portion of the leaf the cross section is uniform, and equations (22) to (24a) for the No. 1 point apply directly.

Second: From $X = l - a$ *to* $X = l$.

For this portion of the leaf it is readily seen that the moment of inertia is:

$$I = I_0 \frac{l + b - x}{a + b}$$

and therefore:

$$\frac{E I_0}{W} \frac{d^2y}{dx^2} = -\frac{(a + b)(l - x)}{l + b - x} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (29)$$

Integrating this equation, and determining the value of the constant of integration from the fact that the value of dy/dx

* Communicated by the Authors.

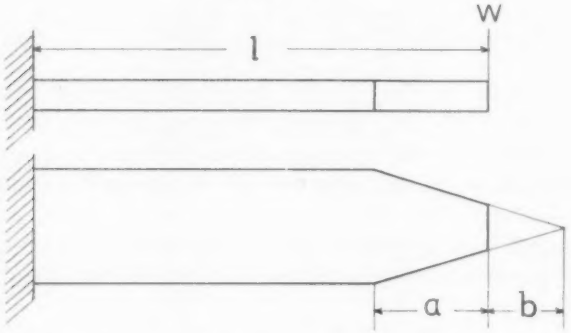
† Concluded from page 721, Vol. 186, December, 1918.

given by the integral for $x = l - a$ must be equal to that given by equation (23) for the same value of x, there results:

$$\frac{EI_0}{W}\frac{dy}{dx} = (a+b)\,x + (a+b)\,b \log \frac{l+b-x}{a+b} + (l-a-b)\,(l-a) - \frac{(l-a)^2}{2} \quad \ldots\ldots (30)$$

Integrating again, and determining the value of the constant of integration from the fact that the value of y given by the

FIG. 18.



integral for $x = l - a$ must be equal to that given by equation (24) for the same value of x, there results:

$$\frac{EI_0}{W}y = (a+b)\frac{x^2}{2} + \left\{\frac{(l-a)^2}{2} - b\,(l+b)\right\}x - (a+b)\,b\,(l+b-x)\log\frac{l+b-x}{a+b} + (a+b)\,b\,(l-a) + \frac{b\,(l-a)^2}{2} - \frac{(l-a)^3}{6} \quad \ldots\ldots (31)$$

When using these equations it must be remembered that the logarithms are natural or hyperbolic ones, to the base e, and not the common logarithms to the base 10.

At the end of the leaf, where $x = l$, the above two equations reduce to:

$$\frac{EI_0}{W}\frac{dy}{dx} = \frac{l^2+a^2}{2} + ab + (a+b)\,b \log \frac{b}{a+b} \quad \ldots\ldots (30a)$$

$$\frac{EI_0}{W}y = \frac{al^2}{2} - \frac{ab\,(a+2b)}{2} + \frac{(l-a)^2\,(2l+a)}{6} - (a+b)\,b^2 \log \frac{b}{a+b} \quad \ldots\ldots (31a)$$

These equations for point No. 2 are very much more complex than are the corresponding ones for point No. 1, but there is no real difficulty in applying them to any particular case—it being merely a matter of arithmetical work. For the sake of uniformity and in order that comparisons may be made, we now apply these equations to the spring shown in Fig. 19, which is the same as that of Fig. 17 except that the leaves have been given a No. 2 taper.

Plate No. 1.

We have $l = 4$, $a = 1.5$, and $b = 1$; and on inserting these values into equation (31a) there results:

$$\frac{EI_1}{W_1} y_1 = \frac{1.5 \times 4^2}{2} - \frac{1.5 \times 1\,(1.5 + 2 \times 1)}{2} + \frac{(4 - 1.5)^2(8 + 1.5)}{6} - (1.5 + 1) \log \frac{1}{1.5 + 1}$$

$$= 21.5636$$

and since $EI_1 = 30772$ (see example of point No. 1 for I, etc.) we have $y_1 = .0007008\ W_1$, or

$$A_1 = .0007008.$$
$$A_2 = 0 \text{ as always.}$$

Plate No. 2.

The reaction W_1 is applied to the non-tapered portion of plate No. 2, so that A_3 and A_4 will be the same as in the example of the No. 1 point, that is:

$$A_3 = .0004366$$
$$A_4 = .0007641$$

For A_5 we have $l = 6$, $a = 1.5$ and $b = 1$ as before, and on inserting these values in equation (31a) it will be found that

$$y_5 = .001478\ W_2$$

or

$$A_5 = .001478$$
$$A_6 = A_4 = .0007641$$

Plate No. 3.

For A_7 and A_8 the reaction W_2 acts at $l_2 = 6$, and from Fig. 19 it will be seen that in this case $a = .5$ and $b = 2$; inserting these values in equation (31a) it will be found that:

$$A_7 = .0009875$$

It will be noticed that the value of A_7 for this case is the same as that found in the previous one, and so it follows that A_8 will be the same as before: if not, then we should have to find the value of dy/dx for $x = l_2 = 6$, multiply this by $l_3 - l_2 = 7 - 6 = 1$ in this case, and add the result to A_7, in order to obtain A_8.

$$A_8 = .001234$$

For A_9 we have W_3 acting at the distance $l = 7$, $a = 1.5$ and $b = 1$, so that, on inserting into equation (31a) and reducing,

$$A_9 = .001571$$
$$A_{10} = A_8 = .001234$$

Making the other calculations, in the same manner as in the previous example, for the No. 1 point, it will be found that:

$$B_1 = .0007008$$
$$C_1 = .6718$$
$$B_2 = .0009647$$
$$C_2 = .6321$$
$$B_3 = .0007910$$
$$W_2 = 1.489\ W_1 = 436 \text{ lbs. for } W_1 = 293 \text{ lbs. as before:}$$
$$W_3 = 2.356\ W_1 = 690 \text{ lbs.}$$

also the maximum stress in plate No. 3 will be 106240 lbs. per sq. in. and the stiffness will be 1264 lbs. per inch deflection.

On comparing these results with those for the No. 1 point it will be found that the differences are negligible, so that we may state definitely that the No. 2 point, of proportions as generally found in practice, has no advantage whatever and that it is a waste of time and money to trim the points to this shape. The only advantage of the No. 2 point over the No. 1 is that of appearance—it pleases some people—but is really of no benefit as regards the endurance of the spring.

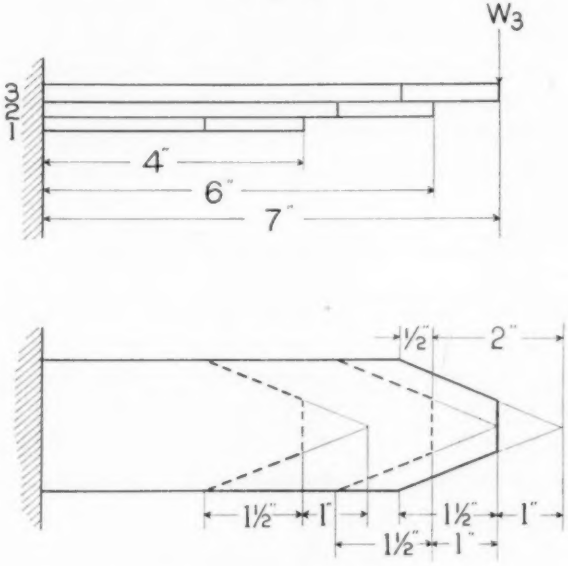
With an actual spring of course the master leaf must have a square point instead of the No. 2 point shown in Fig. 19; this simply means that the equations (22) to (24a) for the No. 1 point must be used when calculating the values of the A's for this leaf.

It seems opportune here to mention a point with regard to the particular equations to be used in certain cases, which, though not really difficult of comprehension, has nevertheless, been found to cause a certain amount of misunderstanding.

The trap point, or any other taper, may have any one of three forms: first, *the taper may be shorter than the overhang*; second, *the taper may be equal to the overhang;* and third, *the taper may be longer than the overhang.* These three cases are shown in Fig. 20, where they are marked *A, B,* and *C,* respectively.

For both the first and the second cases, when finding the *A*'s for the "plate above," referring to the reaction from the "plate below," it must be noticed that the reaction from the plate below is applied to the untapered portion of the plate above, and

FIG. 19.



so the equations for the square-end plates (22) to (24a) must be used: it is well to observe that Case B is the limit of Case A. For the third case, where the tapers overlap, the equations for the No. 2 point must be used, that is, equations (29) to (31a).

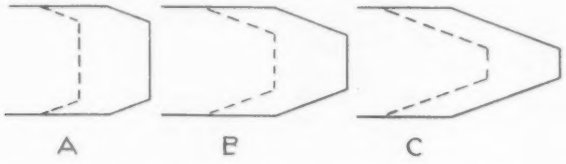
THE HISTORICAL PLATE SPRING—THE BASIC CASE OF THE OLD THEORY.

The historical case of plates of the same cross section, with equal steps, and linear tapers (tapers in width) ending in points at the end of the step as shown in Fig. 12, comes under this section, and although a spring of this kind is only of academic interest, still, considering the fact that practically all of the com-

monly accepted formulæ refer only to this special case, and also bearing in mind that it is of historical importance, it seems desirable to consider it from the viewpoint of the new theory, and, at the same time, to show that the new theory is in perfect agreement with the old one (formulated by the leading mathematicians of their day) for this special case. The new theory does not attempt in any way to overthrow the old one—in fact confirms it by showing its limitation—but the new theory shows that the old one is but a special case only, and one that never occurs in practice.

The new theory is so general in its scope as to cover actual practical conditions, and the relation of the new theory to the old one may be compared with that of Laurent's theorem to

FIG. 20.



McLaurin's—the former is more general, and includes the latter.

In order to prove the statements regarding the equality of the reactions in the special case (Fig. 12) mentioned, a separate analysis appears to us to be the more direct way of proof. The fundamental condition is evidently that $\frac{M}{I}$ = constant, so that, for the tapered portion of the leaves:

$$\frac{EI_{n+1}}{W_{n+1}} \frac{d^2y}{dx^2} = l_{n+1} - l_n$$

Integrating this expression, and proceeding in the same manner as when obtaining equation (7), it will be found that the fundamental relation in this case is:

$$6E\delta_n = \frac{W_n(3l^2_n - 3l^2_n l_{n-1} + 3l_n l^2_{n-1} - l^3_{n-1}) + W_{n-1}(-3l_n l^2_{n-1} + l^3_{n-1})}{I_n}$$

$$= \frac{W_{n+1}(3l^2_n l_{n+1} - l^3_n) - 2W_n l^3_n}{I_{n+1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (32)$$

With plates of equal cross section ($I_{n+1} = I_n$) and equal steps ($l_n = nl_1$) the above equation reduces to:

$$W_n(4n^3 + 1) + W_{n-1}(-2n^3 + 3n^2 - 1) = W_{n+1}(2n^3 + 3n^2) \quad \ldots\ldots\ldots\ldots (33)$$

Putting $n = 1$ in this expression shows that $W_2 = W_1$: then putting $W_n = W_{n-1}$ shows that $W_{n+1} = W_n$, so it follows, from the inductive method of proof, that all of the W's are equal, and so as a consequence are all of the stresses.

For this special case, the deflection relation reduces to:

$$\delta_n = \frac{WP_n}{2nEI} \quad \ldots\ldots (34)$$

which shows that the deflection of a laminated spring of this type is 50 per cent. more than that of a plain plate with a moment of inertia equal to the sum of the moments of inertia of the plates forming the spring. This equation (34) is the ordinary formula of the academic texts.

There seems no further need to enlarge on this point; it is introduced simply on account of its historical importance, and in order to show that the new theory includes the old one as a special case.

FURTHER INVESTIGATION OF TAPERS.

We now pass on to the study of the other types of points:

No. 3 or Round Leaf Point.

It will readily be seen that the effect of this type of point on the stress and deflection relations of a spring is even less than that of the No. 2 point, and the same conclusions hold. All calculations for this type of point may be made by the equations given for the No. 1 point, with the assurance that they will be correct to at least four figures, which is ample for all practical purposes.

No. 4 or Circular Leaf Point.

The remarks made about the No. 3 point apply equally to this type. Exact calculations have been made for the No. 4 point, and they show that, for a leaf of which the length is double the width, the deflection at the end is almost exactly 1 in 1000 more than for a similar square-end leaf; this amount, which is already negligible for practical considerations, decreases directly as the cube of the length increases, so that the effect of this type of taper on an actual spring leaf is absolutely negligible.

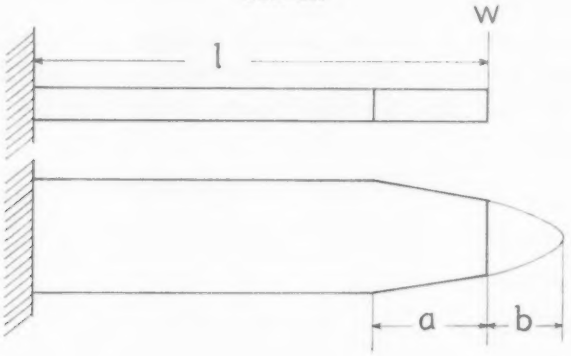
No. 5 or Parabolic Leaf Point.

This type of point is shown on a larger scale in Fig. 21, on which are also given the symbols which will be used in the analysis. The end of the leaf is of uniform thickness with the central portion, but it is cut to a parabolic form in the plane of the width. The effect of this taper is comparable with that of the No. 2 point, and is not usually of any importance.

In order to determine the deflections of leaves with the No. 5 point we have:

First: From $x = 0$ to $x = l - a$.

FIG. 21.



For this portion of the leaf the cross section is uniform, and equations (22) to (24a) for the No. 1 point apply directly.

Second: From $x = l - a$ to $x = l$.

For this portion of the leaf it is readily seen that the moment of inertia is:

$$I = I_0 \left(\frac{l + b - x}{a + b} \right)^{\frac{1}{2}}$$

and therefore:

$$\frac{EI_0}{W} \frac{d^2y}{dx^2} \quad \frac{(a+b)^{\frac{1}{2}} \ (l-x)}{(l+b-x)^{\frac{1}{2}}} \qquad \ldots\ldots(35)$$

$$\frac{EI_0}{W} \frac{dy}{dx} = (a+b)^{\frac{1}{2}} \left\{ 2b \ (l+b-x)^{\frac{1}{2}} - \frac{2}{3} (l+b-x)^{\frac{3}{2}} \right\} + C_1 \qquad \ldots\ldots(36)$$

$$\frac{EI_0}{W} y = (a+b)^{\frac{1}{2}} \left\{ -\frac{4}{3} b \ (l+b-x)^{\frac{3}{2}} + \frac{4}{15} (l+b-x)^{\frac{5}{2}} \right\} + C_1 x + C_2 \qquad \ldots\ldots(37)$$

where:

$$C_1 = \frac{1}{2}(l-a)(l+a) + \frac{2}{3}(a+b)(a-2b) \quad \ldots\ldots(38)$$

$$C_2 = \frac{4}{15}(a+b)^2(4b-a) - \frac{1}{6}(l-a)^2(l+2a) - \frac{2}{3}(a+b)(a-2b)(l-a) \quad \ldots\ldots(39)$$

At the end of the leaf, where $x = l$, equations (36) and (37) reduce to:

$$\frac{EI_0}{W}\frac{dy}{dx} = \frac{4}{3}(a+b)^{\frac{1}{2}}b^{\frac{3}{2}} + C_1 \quad \ldots\ldots(36a)$$

$$\frac{EI_0}{W}y = -\frac{16}{15}(a+b)^{\frac{1}{2}}b^{\frac{5}{2}} + C_1 l + C_2 \quad \ldots\ldots(37a)$$

When $b = 0$ we have:

$$\frac{EI_0}{W}y = \frac{4}{15}a^{\frac{1}{2}}(l-x)^{\frac{5}{2}} + C_1 x + C_2 \quad \ldots\ldots(37b)$$

$$C_1 = \frac{1}{2}l^2 + \frac{1}{6}a^2 \quad \ldots\ldots(38a)$$

$$C_2 = \frac{1}{15}a^3 - \frac{1}{6}l(l+a)(l-a) \quad \ldots\ldots(39a)$$

and when $b = 0$ and $x = l$;

$$\frac{EI_0}{W}y = \frac{1}{3}l^3 + \frac{1}{15}a^3 \quad \ldots\ldots(37c)$$

As an example, if we apply equation (37c) to the bottom leaf of the spring of Fig. 17, making $a = 1.5''$ (the length used for the spring of Fig. 19) and $b = 0$, we find that $A_1 = .0007005$, as against .0006933 for the spring of Fig. 17 with the No. 1 point and .0007008 for the spring of Fig. 19 with the No. 2 point: in this case it is seen that the parabolic point makes even less difference than does the trap' point; in other cases the effect may be greater but it is never of any commercial importance.

The result of the foregoing analysis of *the effects of tapering the points of the leaves of leaf springs in the plane of the width only* may be said to be that *such tapering has no practical effect on the strengths, reactions, stresses, or flexibilities of the springs*—in fact, aside from the æsthetic point of view, such tapering is of no practical use and it is a waste of money to perform the operations incidental to their manufacture. The special

"point trimming dies" are expensive to make and to keep in order, while the final result is simply that the springs *"look"* a little different from those with square pointed leaves.

We may here find the theoretical explanation of the observed practical fact that the heavy railroad and truck springs are usually made with square points, which are found to give just as good results in use as do those with sheared taper points.

With the advent of the reduction of costs of such modern appliances as the automobile came the demand, within the past three to four years, for reducing the costs of motor car springs.

As one of the costliest operations in spring manufacturing is the leaf tapering operation, some spring manufacturers at first decided to do away with tapering altogether. We have seen this practiced by at least one large automobile company—that is using a square end. Looks probably had much to do in discouraging the non-tapered springs, and as a substitute, and nearly equal in cost to the plain end, is the trapezoidal taper now found on many cars.

We have here an illustration in the use of "trap" points to make the eye believe that this is "as good" in results as the regular thickness tapering. The lack of analysis of these tapers has enabled the spring makers to dispose of an inferior product at a fair price with the assumption that the product was first class.

It is not our wish to have the reader infer that the spring maker really knew that trap' points were inferior to thickness tapers (indeed he cannot say what physical changes are produced by tapering) but we do wish to point out that springs of this kind are more economical to manufacture and they have not the "life" of the thickness tapered variety. We believe that this is the first time and place in which the illusion has been dispelled and the spring maker and spring user are herein given a clear answer to this question.[1]

We now proceed to the study of spring leaves which are

[1] The United States Government Liberty Truck Springs, Class B, are excellent illustrations of the inefficient use of material due to lack of this knowledge concerning tapers on the part of those who have "designed" these members.

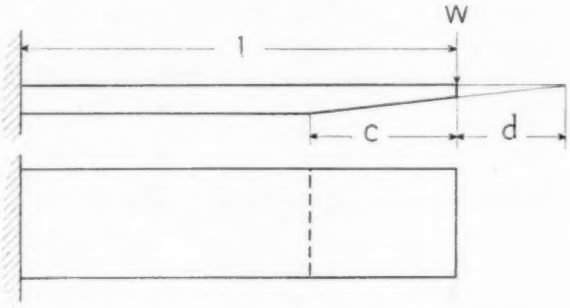
tapered in the plane of the thickness, and the first case is that of the:

No. 6 or Square-tapered Leaf Point.

This is the first case of tapering where the result is of real importance and has any considerable effect on the spring. The leaf is simply cut off square in the width, but it is tapered in the plane of the thickness. This point is shown on a larger scale in Fig. 22, on which are also given the symbols which will be used in the analysis.

In order to determine the deflections of leaves with the No. 6 point we have:

FIG. 22.



First, From $x = o$ to $x = l - c$.

For this portion of the leaf the cross section is uniform, and equations (22) to (24a) for the No. 1 point apply directly.

Second, From $x = l - c$ to $x = l$.

For this portion of the leaf it is readily seen that the moment of inertia is:

$$I = I_0 \frac{(l+d-x)^3}{(c+d)^3}$$

and therefore:

$$\frac{EI_0}{W}\frac{d^2y}{dx^2} = \frac{(c+d)^3(l-x)}{(l+d-x)^3} \quad \ldots\ldots (40)$$

$$\frac{EI_0}{W}\frac{dy}{dx} = (c+d)^3\left\{\frac{-d}{2(l+d-x)^2} + \frac{1}{(l+d-x)}\right\} + C_1 \quad \ldots\ldots (41)$$

$$\frac{EI_0}{W}y = (c+d)^3\left\{\frac{-d}{2(l+d-x)} - \log(l+d-x)\right\} + C_1 x + C_2 \quad \ldots\ldots (42)$$

where:

$$C_1 = \frac{1}{2}(l^2 - 3c^2 - 3cd - d^2) \quad \ldots\ldots (43)$$

$$C_2 = \frac{1}{6}\left\{ -l^3 + 3l(3c^2+3cd+d^2) - 2c^3(4c+3d) + 3d^3(c+d) + 6(c+d)^3 \log(c+d) \right\} \quad \ldots\ldots (44)$$

At the end of the leaf, where $x = l$, equations (41) and (42) reduce to:

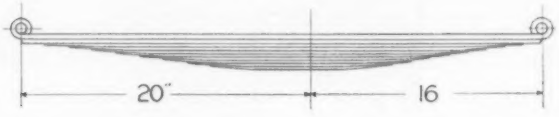
$$\frac{EI_0}{W}\frac{dy}{dx} = \frac{(c+d)^3}{2d} + C_1 \quad \ldots\ldots (41a)$$

$$\frac{EI}{W}y = (c+d)^3\left(-\frac{1}{2} - \log d\right) + C_1 l + C_2 \quad \ldots\ldots (42a)$$

The logarithms are of course natural or hyperbolic.

These equations (40) to (42a) may be said to be the most important of all in the theory of leaf springs. Unfortunately they are somewhat complex, but still there is no real difficulty

FIG. 23.



in applying them to practical cases, as will be shown shortly. The work is admittedly tedious, but that is all, and the results are of such great importance that the mere labor of arithmetical computation becomes a minor consideration. For regular commercial work, tables can be—and have been—calculated which greatly reduce the work, and with the aid of these tables it does not take long (considering the value of the results) to work out completely any given spring.

It has already been shown that a taper in the width only has scarcely any effect on a spring. A taper in the thickness, on the other hand, has an enormous effect, as will shortly be shown by the application of the above equations for the No. 6 point. A combination of the two tapers—in the width and in the thickness—is sometimes of much importance, but in general the effect of the taper in the width is very much less than that of the taper in the thickness. The equations for the leaf point No. 6 may be said to be of fundamental importance as regards the application of the new theory of leaf springs to practical springs.

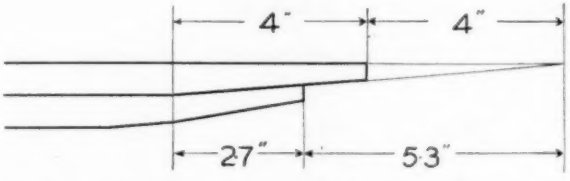
The No. 6 leaf point is of such great importance that we here give an example taken from practice instead of an academic case of a spring with only two or three leaves. This spring, which was used on one of the American automobiles, is shown in Fig. 23, and the details of the tapering are shown in Fig. 24. The details of the shorter (16″) end, so far as required for present purposes, are given in the following table:

Details of the Spring Shown in Fig. 23.

n	l_n	I_n	z_n
1	5.6	.001215	.01197
2	6.9	.001215	.01197
3	8.2	.001215	.01197
4	9.5	.001215	.01197
5	10.8	.001215	.01197
6	12.1	.001215	.01197
7	13.4	.001557	.01415
8	14.7	.001982	.01665
9	16.0	.002566	.01982
10	16.0	.004013	.02675

Plate No. 9 (the long plate) is not tapered, and for the purpose of calculating the reactions, plates Nos. 9 and 10 must be taken together and considered as one plate, with a moment of inertia equal to the sum of the moments of inertia of each—that is $(.002566 + .004013) = .006579$.

FIG. 24.



It will be noticed that the overhangs, after the first, are all 1.3″ and that the tapers at the ends of the leaves are $c = d = 4''$. There are then only two cases to which we have to apply the taper equations: first, for the case where we are dealing with the reactions on the end of a leaf, when $c = d = 4$; and, second, when we are dealing with the reaction on a leaf from the "plate below," in which case the reaction acts at a distance of 1.3″ from the end of the leaf, so that we have $c = 2.7''$ and $d = 5.3''$, as is indicated in Fig. 24.

A study of equations (40) to (42a) will show that they may be considerably reduced for the numerical work in the following manner when the tapers are the same:

First, for $c = d = 4$.

On inserting these values of c and d into equations (43), (44) and (42a) there results:

$$C_1 = \frac{1}{2}(l^2 - 112)$$

$$C_2 = \frac{1}{6}(-l^3 + 336\,l + 5876)$$

for $x = l$,

$$\frac{EI}{W}\,y = -965.78 + C_1 l + C_2$$

Second, for $c = 2.7$, $d = 5.3$.

$$C_1 = \frac{1}{2}(l^2 - 92.89)$$

$$C_2 = \frac{1}{6}(-l^3 + 278.67\,l + 6672.9)$$

for $x = l$,

$$\frac{EI}{W}\frac{dy}{dx} = 48.302 + C_1$$

$$\frac{EI}{W}\,y = -1109.86 + C_1 l + C_2$$

Using these reduced expressions, the values of the various C's are readily calculated on inserting the various values of the l's; they will be found to be as follows:

	$c = d = 4$		$c = 2.7,\ d = 5.3$	
n	C_1	C_2	C_1	C_2
1	−40.320	1263.7	−30.765	1342.9
2	−32.195	1311.0	−22.640	1377.8
3	−22.380	1346.6	−12.825	1401.0
4	−10.875	1368.4	− 1.320	1410.4
5	2.320	1374.2	11.875	1403.7
6	17.205	1361.7	26.760	1378.7
7	33.780	1328.7	43.335	1333.3
8	52.045	1273.1		

Now using these values for the C's the various deflection relations may readily be calculated, giving the values of the A's, after which the B's and C's for the spring are to be found in the same manner as in the earlier example. It must, of course, be

noted that the C's of equation (12) for the spring are not the C's of the above table; in the table the C's are the constants of integration as found from equations (43) and (44), while the C's for the spring are those found from equation (12). The use of the same symbol for denoting the two different things will not be found to cause any trouble in practice. The results of the calculations show that the various constants for the spring have the values given in the following table:

n	A_n	B_n	C_n	W_n
1	.00212	.00212	.631	1.000
2	.00000	.00207	.795	1.585
3	.00178	.00241	.869	1.993
4	.00245	.00288	.904	2.294
5	.00362	.00345	.930	2.537
6	.00245	.00410	.895	2.728
7	.00328	.00455	.871	3.049
8	.00426	.00481	.617	3.500
9	.00580	.00339		5.673
11	.00546			
12	.00682			
13	.00880			
15	.00846			
16	.01025			
17	.01271			
19	.01235			
20	.01465			
21	.01772			
23	.01360			
24	.01584			
25	.01871			
27	.01448			
28	.01662			
29	.01930			
31	.00575			
32	.00651			
33	.00741			

The values of A_{10}, A_{14}, etc., have not been given in the table, as they are respectively equal to A_8, A_{12}, etc., according to the theorem.

If we allow a stress of 100,000 lbs. per sq. in. in the bottom or short leaf, then the safe load on it will be $(100000 \times .01197)/5.6 = 214$ lbs. and the corresponding load on the short end of the

spring, or W_9, will be $214 \times 5.673 = 1210$ lbs. The stiffness $= 1/B_9 = 1/.00339 = 295$ lbs. load per inch deflection. Allowing for the difference in the lengths of the two ends of the actual spring, this stiffness of the short end corresponds to a stiffness of 425 lbs. per inch for the entire spring.[2] All of the above figures have been calculated on the assumption that $E = 28 \times 10^6$, but a number of tests made some years ago showed that on an average E is slightly under 29×10^6, and adjusting the stiffness to this latter figure for E, it will be found that the calculated stiffness is 440 lbs. per inch. The average test of several hundreds of these springs showed that the stiffness was 447 lbs. per inch, so that the agreement is very good indeed, the difference being well under 2 per cent., while commercial springs of the same batch will at times vary five per cent., as a maximum. The agreement is, therefore, within the limits of manufacturing accuracy.

In order to complete the study of this spring, we must calculate the stresses in the various plates. The lower plates present no difficulty and for the top "compound plate" the load carried by each of the two plates is directly proportional to its moment of inertia, so that the thick plate No. 10 carries $1210 \times .004013/.006579 = 740$ lbs. and the thinner plate No. 9 carries the remainder, or 470 lbs. On performing the necessary calculations it will be found that the maximum stresses in the various plates at the centre point of encastrèment, are as follows:

Plate No.	*Stress.*
1	100000
2	95500
3	96600
4	97500
5	100000
6	100000
7	119000
8	106000
9	165000
10	192000

[2] For a complete study of the deflection of an excentrated spring the reader is referred to an article entitled, "The Partial and Total Deflections of Leaf Springs En Masse," in the *Horseless Age*, January 20, 1915; January 27, February 10, February 17, February 24, March 3, March 17, March 24, 1915, by David Landau and Asher Golden.

from which it will be seen that the greatest stress in this spring occurs in the top or master leaf. If the maximum stress in the spring is to be limited to 100,000 lbs. per sq. in. then the safe load on the short end will evidently be $1210 \times 100000/192000 = 630$ lbs., which will give the allowed stress in the master leaf, the stresses in the lower leaves being then all smaller; the total safe load on the spring on the same basis being 1133 lbs.

The taper which is now under consideration is so important that it appears to be advisable to work out this spring on the assumption that the leaves have square points (No. 1) in order to show the great difference made by the tapering. If this spring is worked out by the equations for the square point, it will be found that the reactions, etc., are as follows:

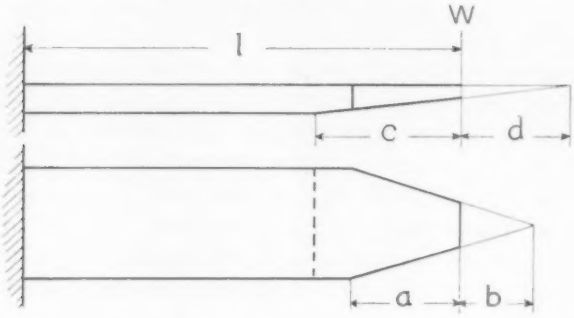
n	W_n	Stress
1	1.00	100000
2	1.49	83700
3	1.76	74100
4	1.93	69800
5	2.03	64100
6	2.11	64500
7	2.26	71900
8	2.48	79200
9	3.74	98800
10		114000

The total safe load on the short end of the spring with a stress of 100000 in the short leaf is 800 lbs. and with the same stress in the master leaf it is 700 lbs. while the stiffness of the short end is 321 lbs. per inch; this is a total spring stiffness of 479 lbs. per inch, and a total safe load of 1225 lbs.

A comparison of these figures with the corresponding ones for the tapered ends shows that the differences are very great; the final reaction in the case of the tapered spring has been increased by over fifty per cent., and the stress in the master leaf by nearly seventy per cent. With the trap', and other types of points which are tapered in the width only, the difference due to tapering has been shown to be in the neighborhood of only one per cent., so that they are of no practical value, but the above example shows that tapering in the thickness may produce relatively enormous effects and that almost any kind of stress distribution can be obtained by a suitable combination of tapering

in the thickness and grading. It is not suggested that the particular example chosen for illustration is a good one; in fact, it will be seen that the safe load for the tapered spring in this particular case is slightly less than for the non-tapered one, though the tapered spring is the more flexible. This spring is an old design, produced sometime before the full effects of tapering were properly appreciated, with the consequence that the stresses in the upper part of the springs were somewhat excessive and in use the master leaves were generally the first to break. By properly adjusting the tapers, the stresses can be made very nearly equal throughout the spring, with a corresponding benefit, for in this case all of the metal is used to the greatest possible

FIG. 25.



advantage. There are other modifying circumstances, which will be dealt with in our third paper, which tend to increase the stresses in the lower leaves and decrease them in the upper leaves, so that, ultimately, the stress distribution is better than would appear from the above figures for the tapered leaves and actually the tapered leaf spring is better than the untapered one, though the above figures tend to show the reverse.

We now pass on to the study of the leaves which are tapered in the plane of the width as well as in the plane of thickness.

No. 7 or Trapezoidal-tapered Leaf Point:

This type of point is shown on a larger scale in Fig. 25, which figure also shows the symbols which will be used in the analysis. The effects of the taper in the width are usually of secondary importance as compared with the effects of the taper

in the thickness, but, nevertheless, there are cases where they are considerable.

In order to find the deflections of leaves with the No. 7 point we must note that there are several possible cases: for the present the two cases which have to be noticed are those for which $c>a$ and for which $c<a$. The first case, which is the most usual one, is shown in Fig. 25, and for this it will be noticed that from $x=0$ to $x=l-c$ the cross section of the plate is uniform, so that equations (22) to (24a) for the No. 1 point apply directly. From $x=l-c$ to $x=l-a$ the plate is of uniform width, but has a taper in the thickness, so that the equations for the No. 6 point must be used for this portion of the leaf. From $x=l-a$ to $x=l$ there is the double taper, for which taper we are now going to find the equations. For the second case, where $c<a$, it will easily be seen that for the portion of the leaf between $x=l-a$ and $x=l-c$ the thickness of the leaf is constant but the width is tapered, so that the equations for the No. 2 point are directly applicable to this portion of the leaf.

For the Double Taper of Fig. 25, from $x=l-a$ to $x=l$.

For this portion of the leaf, it is readily seen that:

$$I = I_0 \left(\frac{l+b-x}{a+b}\right)\left(\frac{l+d-x}{c+d}\right)$$

so that:

$$\frac{EI_0}{W}\frac{d^2y}{dx^2} = \left(\frac{a+b}{l+b-x}\right)\left(\frac{c+d}{l+d-x}\right)^3 (l-x) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (45)$$

In order to integrate this expression, it seems best first to put into the equivalent form:

$$\frac{EI_0}{W}\frac{d^2y}{dx^2} = (a+b)(c+d)^3 \left\{\frac{1}{l+b-x}\right\}\left\{\frac{-d}{(l+d-x)^3} + \frac{1}{(l+d-x)^2}\right\}$$

Then if we put:

$$z = \frac{l+b-x}{l+d-x}$$

we find that, so long as b is not equal to d:

$$x = l+d-\frac{d-b}{(1-z)}$$

and

$$dx = -\frac{d-b}{(1-z)^2}\,dz$$

also:

$$l+b-x = \frac{(d-b)z}{1-z} \text{ and } l+d-x = \frac{d-b}{1-z}$$

whence, after integrating:

$$\frac{EI_0}{W}\frac{dy}{dx}=\frac{(a+b)\,(c+d)^3}{(d-b)^3}\left\{\frac{dz^2}{2}-(d+b)\,z+b\log z\right\}+C_1 \quad \ldots\ldots (46)$$

For the cases where the points of the leaves are tapered in both the width and in the thickness, the mathematical expressions for the constants (C's) of integration become so complex that it does not appear to be useful to give them; it seems to be better to evaluate them numerically when required. It is evident from considerations of continuity, that for the leaf point of Fig. 25, the value of dy/dx given by equation (46) for $x=l-a$, where the double taper commences, must be equal to the value of dy/dx given by equation (41) for the shorter portion of the leaf, for the same value of x. The procedure for finding C_1 is therefore to calculate the value of dy/dx for $x=l-a$ by means of equation (41) and then to insert this value in the left hand side of equation (46), which, combined with $x=l-a$ on the right-hand side, allows of the value of C_1 being calculated.

A second application of the substitution used for integrating equation (45) allows of integrating the integral equation (46), and, after absorbing the constant part of x into the constant of integration C_2, we obtain:

$$\frac{EI_0}{W}y=-\frac{(a+b)\,(c+d)^3}{(d-b)^2}\left\{d\left(z-\frac{1}{1-z}\right)+\frac{2b}{1-z}(z\log z-1)\right\}$$
$$-\frac{d-b}{1-z}\times C_1+C_2 \quad \ldots\ldots (47)$$

C_2 must be found in the same manner as described for C_1, by equating the values of y from equations (42) and (47) for $x=l-a$. For the other cases, if $c=a$, it will readily be seen that the equations for point No. 1 must be used for comparison when determining the values of the C's and if $c<a$, then the equations for point No. 2 must be used, instead of those for the No. 6 point referred to in the preceding analysis.

We must now consider the *special case where* $b=d$, for which the preceding analysis fails to give the result. For this particular case we have:

$$\frac{EI_0}{W}\frac{d^2y}{dx^2}=(a+b)\,(c+d)^3\,\frac{(l-x)}{(l+b-x)^4} \quad \ldots\ldots (48)$$

$$\frac{EI_0}{W}\frac{dy}{dx}=(a+b)\,(c+d)^3\left\{\frac{-b}{3\,(l+b-x)^3}+\frac{1}{2\,(l+b-x)^2}\right\}+C_1 \quad \ldots\ldots (49)$$

$$\frac{EI_0}{W}y=(a+b)\,(c+d)^3\left\{\frac{-b}{6\,(l+b-x)^2}+\frac{1}{2\,(l+b-x)}\right\}+C_1x+C_2 \quad \ldots (50)$$

This concludes our study of the No. 7 point, for which it does not appear to be necessary to give a numerical example, and we at once pass on to the consideration of the remaining types of double tapered leaf points.

No. 8 or Round-tapered Leaf Point.

The remarks made with reference to the No. 3 point apply also to this type of point—the effect of the rounding is absolutely negligible: the tapering in the thickness is very important, but the effect of the rounding is ***nil***, so that the reactions, etc., for this type of point may for all practical purposes be calculated by means of the equations for point No. 6.

No. 9 or Circular-tapered Leaf Point.

The remarks made above regarding the No. 8 point apply, without modification, to this type of point. The rounding of the ends of the leaves with the No. 8 and No. 9 points may, perhaps, improve the appearance of the springs, but it has no effect on the strengths, flexibilities or endurances.

No. 10 or Parabolic-tapered Leaf Point.

This "double-tapered" type of leaf point is of more importance than the others, especially when combined with a "stress-equalizing slot," and is the subject of several patents in connection with plate springs.[3] The taper in the thickness has much more effect than has that in the width, but still, the effect of the taper in the width cannot be ignored. This point is shown on a larger scale in Fig. 26, where also are indicated the symbols

[3] The reader may find it to his interest to peruse the patents which resulted from the research work contained in these papers. We direct attention to the following American patents, all issued in the name of David Landau:

Name of Patent	Date of Issue	Patent No.
Laminated Spring	Sept. 19, 1916	1,199,038
Laminated Spring	Sept. 19, 1916	1,199,013
Laminated Spring	Oct. 2, 1917	1,241,743
Spring	Oct. 2, 1917	1,241,744

Similar patents, in whole or in part, have been issued in Canada, France, Spain, Italy and England. Patents are also pending in Belgium, Russia, Canada and England. Applications were instituted in Germany prior to the war—at present these are withheld.

which will be used in the analysis. As with the point No. 7, there are several posssible cases according as to whether a is less than, equal to, or greater than c: these variations, however do not cause any trouble in application, since it is merely a matter of selecting from the equations given earlier in the paper those applying to the portion of the leaves before the double taper commences.

In order to determine the deflections of the leaves with the No. 10 point, we see on referring to Fig. 26, that from $x = l - a$, where the double taper commences:

$$I = I_0 \left(\frac{l + b - x}{a + b}\right)^{\frac{1}{2}} \left(\frac{l + d - x}{c + d}\right)^3$$

so that:

$$\frac{EI_0}{W}\frac{d^2y}{dx^2} = \left(\frac{a + b}{l + b - x}\right)^{\frac{1}{2}} \left(\frac{c + d}{l + d - x}\right)^3 \left(l - x\right) = (c + d)^3 \left(\frac{a + b}{l + b - x}\right)^{\frac{1}{2}}$$

$$\left(\frac{-d}{(l + d - x)^3} + \frac{1}{(l + d - x)^2}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (51)$$

This expression is not an easy one to integrate, but so long as $b < d$, which is always the case in the practical spring, it may be integrated by means of the substitution:

$$l + b - x = (l + d - x) \sin^2 \theta,$$

by the use of which we have:

$$-x = (d - b) \tan^2 \theta - (l + b)$$

$$dx = -2\,(d - b) \tan \theta \sec^2 \theta\, d\theta$$

$$l + b - x = (d - b) \tan^2 \theta$$

$$l + d - x = (d - b) \sec^2 \theta$$

$$\sin^2 \theta = \frac{l + b - x}{l + d - x}$$

$$\cos^2 \theta = \frac{d - b}{l + d - x}$$

$$\tan^2 \theta = \frac{l + b - x}{d - b}$$

$$\sin \theta \cos \theta = \frac{(l + b - x)^{\frac{1}{2}}\,(d - b)^{\frac{1}{2}}}{l + d - x}$$

$$\frac{dx}{(l + b - x)^{\frac{1}{2}}\,(l + d - x)^2} = \frac{-2 \cos^4 \theta\, d\theta}{(d - b)^{\frac{1}{2}}}$$

$$\frac{dx}{(l + b - x)^{\frac{1}{2}}\,(l + d - x)^2} = \frac{-2 \cos^2 \theta\, d\theta}{(d - b)^{\frac{1}{2}}}$$

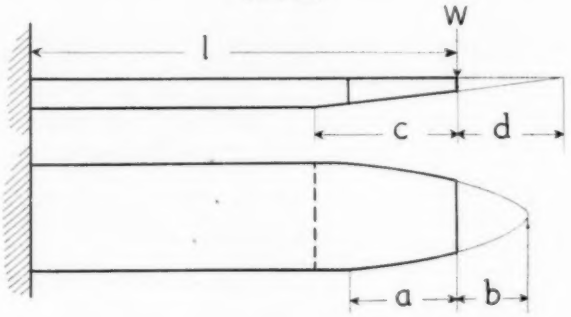
Using these relations, it will be found that:

$$\frac{EI_0}{W}\frac{dy}{dx} = \frac{(a+b)^{\frac{1}{2}}(c+d)^3}{4(d-b)^{\frac{3}{2}}}\left\{(4b-d)(\sin\theta\cos\theta+\theta)+2d\sin\theta\cos^2\theta\right\}+C_1. \quad (52)$$

where C_1 must be determined in the manner explained for the leaf point No. 7, by comparing the values of dy/dx from the equation corresponding to the first portion of the leaf with that given by the above equation.

A second application of the same transformation will enable equation (52) to be integrated in order to determine the

FIG. 26.



value of y, and the result, after absorbing the constant part of x into C_2 will be found to be:

$$\frac{EI_0}{W}y = -\frac{(a+b)^{\frac{1}{2}}(c+d)^3}{4(d-b)^{\frac{3}{2}}}\left\{(4b-d)(\theta\tan^2\theta+\tan\theta-\theta)+\right.$$
$$\left.2d(\theta-\sin\theta\times\cos\theta)\right\}-C_1(d-b)\tan^2\theta+C_2 \quad (53)$$

where, of course, C_2 is to be determined in a similar manner as before.

When using equations (52) and (53), it must be noticed that θ, when standing alone or appearing as a factor, must be expressed in circular measure or radians, since it has made its appearance on account of integrations of circular functions. The value is easily obtained by extracting the square root of $\sin^2\theta$ in order to obtain $\sin\theta$; referring to the ordinary tables of natural sines for the value of θ in degrees, minutes and seconds, and then referring to the table of Circular Measure, given in most books of mathematical tables, one may find the circular measure of the angle.

At the end of the leaf, where $x = l$, the expressions given for the values of the circular trigonometrical functions of θ reduce to:

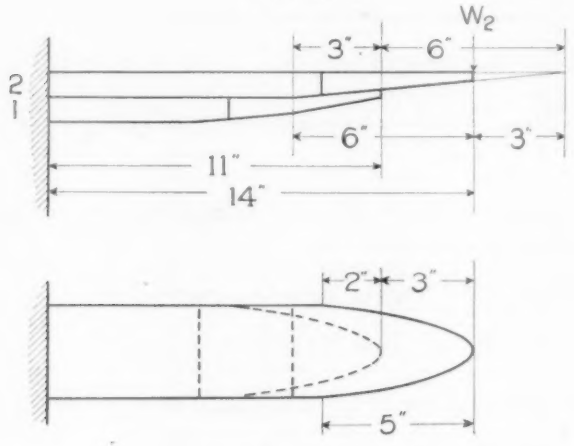
$$\sin^2\theta = b/d$$
$$\cos^2\theta = (d-b)/d$$
$$\tan^2\theta = b/(d-b)$$
$$\sin\theta\cos\theta = b^{\frac{1}{2}}(d-b)^{\frac{1}{2}}/d$$

and when we have $b = 0$, then at the end of the leaf, with $x = l$, the $\theta = 0$ (zero) and equation (53) reduces to the simple form:

$$\frac{EI_0}{W}y = C_2 \qquad \text{(53a)}$$

These expressions are admittedly very complex; in most cases, however, the somewhat simpler equations for the No. 6

FIG. 27.



point will be found to be sufficient to give the required degrees of accuracy, although there are occasions when it is necessary to apply the equations of the present section of this paper. There is no real difficulty in the application, but there is a *very considerable amount* of arithmetical labor; it seems impossible to avoid this, when dealing with these types of "double-taper" points, and so one must be satisfied to perform the laborious numerical work in order to obtain the very important results which may be deduced from their applications.

This type of point (No. 10) being of practical as well as

theoretical importance, a numerical example will be given, although, on account of the very considerable amount of labor involved in working out completely an actual spring, the work here will be confined to two plates only. The two-plate spring for which the calculations will be given here is that shown in Fig. 27; on this figure most of the data necessary for the present purpose will be found. We now proceed to the necessary calculations.

First, for Plate No. 1.

Referring to Fig. 27, it will be seen that the double taper commences at $x = 6$, at which point, on the left-hand side, the equations for point No. 6 hold. It will also be seen that $l_1 = 11$, $a = 5$, $b = 0$, $c = 6$ and $d = 3$.

Now using the equations for the No. 6 type of point for the point $x = 6$ we find that:

$$\text{equation (43) gives } C_1 = -25$$

$$\text{equation (44) gives } C_2 = 1965$$

then using these values:

$$\text{equation (41) gives } \frac{EI_0}{W}\frac{dy}{dx} = 49$$

$$\text{equation (42) gives } \frac{EI_0}{W}y = 162$$

Next inserting the values for *a*, *b*, etc., into the substitution equations for the No. 10 point, it will be found that:

$$\sin^2\theta = .625$$

$$\cos^2\theta = .375$$

$$\tan^2\theta = 1.667 \text{ and } \tan\theta = 1.291$$

$$\sin\theta\cos\theta = .484$$

$$\sin\theta = .79057 \text{ so that } \theta = 52^\circ\,14' = .912 \text{ radians.}$$

We are now in position to determine the values of the constants C_1 and C_2 for the equations for point No. 10, and on referring to equations (50) and (51) it will be seen that we need the values of $\frac{(a+b)^{\frac{1}{2}}(c+d)^3}{4(d-b)^{\frac{5}{2}}}$ and $\frac{(a+b)^{\frac{1}{2}}(c+d)^3}{4(d-b)^{\frac{5}{2}}}$ which will be found to be 26.14 and 78.41 respectively.

Now referring to equation (52) and using the above values, we have:

$$49 = 26.14 \left\{ (4 \times 0 - 3)(.484 + .912) + 2 \times 3 \times .484 \times .375 \right\} + C_1$$

from which:

$$C_2 = 130$$

Next referring to equation (53) and using the above values, we have:

$$162 = -78.41 \left\{ (4 \times 0 - 3)(.912 \times 1.667 + 1.291 - .912) + 2 \times 3 (.912 - .484) \right\} - 130 \times 3 \times 1.667 + C_2$$

from which:

$$C_2 = 567$$

Having now determined the values of the C_1 and C_2 for use in equations (52) and (53) for the short (No. 1) plate, we need, for present purposes, simply to use equation (51a) and note that:

$$y_1 = \frac{567\ W_1}{EI_0}$$

For many cases, especially when the plates are of the same section, as is assumed to be the case in this example, it is convenient to discard the constant factor $1/EI_0$ in the intermediate operations and we may write:

$$y_1 = 567\ W_1 \text{ or } A_1 = 567$$

The discarded factor can be reintroduced at any time when found necessary and, in general, it will be found conducive to accuracy to omit it until it is required for final calculation. Of course, in any case where the cross section of the plate above is different from that of the plate below, it is necessary to introduce either the actual values of the factor or else the ratios of the two I's, the handling of which ratio will often be found to be the best method of procedure in practice, reserving the introduction of the value of E and I_0 until the final deflection relation is required.

We may here note that if there were no taper on this plate, so that it had the (No. 1) square point, the corresponding value of the deflection coefficient would be $11^3/3 = 443$, so that the taper has the effect of adding nearly 30 per cent. to the flexibility in this case.

The calculations for this example have been worked out mostly on a 10″ slide rule, so that it is possible—and even likely—that there are small errors, but these will not be sufficient to affect the general accuracy of the comparisons. For actual work in the spring designing room, where greater accuracy is desired, it is better to work out the results to not less than four, and preferably to five figures by the aid of a calculating machine; for present needs this did not seem to us to be necessary as the results are rather intended to indicate methods and offer general comparisons than to give examples of actual designs.

We now pass on to the calculations for the second plate.

Second, for Plate No. 2 and for the Reaction W_1 Acting at the Distance $l_1 = 11''$.

On referring to Fig. 27 it will be seen that for this section of the calculations, we have $l_1 = 11$, $a = 2$, $b = 3$, $c = 3$ and $d = 6$, while the double taper commences at $x = 9$.

Making use of the above values, we find that:

equation (43) gives $C_1 = 2$, and

equation (44) gives $C_2 = 2095$

then for the point $x = 9$, where the double taper commences,

equation (41) gives $\frac{EI}{W}\frac{dy}{dx} = 59$, and

equation (42) gives $\frac{EI}{W}y = 324$.

It will easily be seen that the angular functions are the same in this as in the first section of the calculations, and the application of equation (52) and the above figures show that the value of C_1 to be used in equations (52) and (53) is -217. Similarly, it will be found that the value of C_2 to be used in equation (53) is 535.

Having now found the values of the two constants C_1 and C_2 of integration for equations (52) and (53), we are in a position to calculate the values of dy/dx and y for plate No. 2 at the point $x = l_1 = 11$.

Using the reduced expressions for the angular functions, it will be found that:

$$\sin^2\theta = \cos^2\theta = \sin\theta\cos\theta = .500$$

$$\tan^2\theta = \tan\theta = 1$$

$$\theta = 45^\circ = .785 \text{ radians.}$$

Making use of these values, equation (52) shows that for $x = 11$ $dy/dx = 63W_1$, omitting the factor $1/EI$ as mentioned before, and equation (53) shows that $y_1 = 447W_1$.

The deflection at the end of plate No. 2, due to the reaction W_1 acting at the distance l_1 is, evidently, making use of the above figures, equal to $(447 + 63 \times 3)\ W_1 = 636W_1$.

Third, for Plate No. 2 and for the Load W_2 acting at the Distance $l_2 = 14''$.

For this section of the calculations it will be seen that $l_2 = 14$, $a = 5$, $b = 0$, $c = 6$, $d = 3$ and the double taper commences at $x = 9$. Using these values we find that:

equation (43) gives $C_1 = 10.5$

equation (44) gives $C_2 = 1986$

then for the point $x = 9$, where the double taper commences,

$$\text{equation (41) gives } \frac{EI}{W}\frac{dy}{dx} = 84, \text{ and}$$

$$\text{equation (42) gives } \frac{EI}{W}y = 447$$

The circular functions are the same as for the first section of the calculations, so that,

equation (52) gives $C_1 = 165$ and equation (53) then gives $C_2 = 1007$.

An examination of the foregoing figures will show that:

$$A_1 = 567;\ A_2 = 0;\ A_3 = 447;\ A_4 = 636;\ A_5 = 1007;\ A_6 = 636,$$

it being of course understood that the factor $1/EI$ has been omitted.

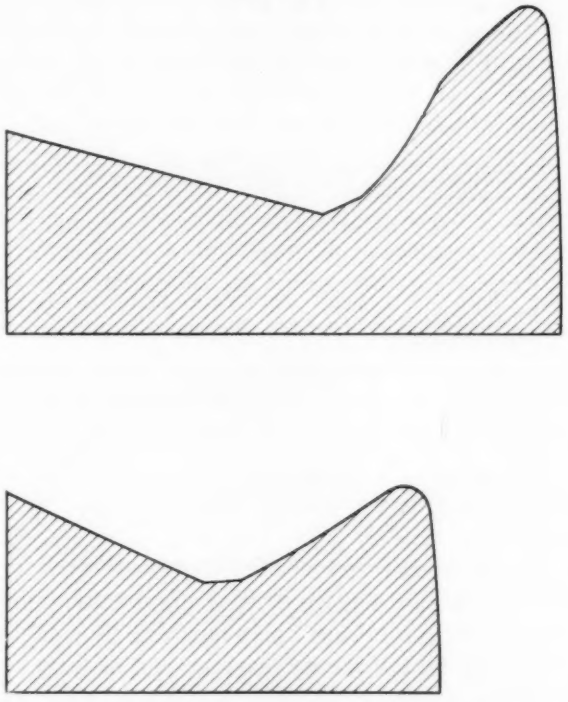
Now proceeding in the same manner as for the previous examples, we find that $B_1 = A_1 = 567$, $C_1 = .6282$, $B_2 = 607$, and for $W_1 = 1.000$ we have $W_2 = 1/.6282 = 1.592$.

Let us now suppose that the plates of the spring are 3″ wide and 3/8″ thick, with $I = .01318$ and $Z = .07032$, and allow a maximum stress in the bottom or No. 1 plate of 100,000 lbs. per sq. in. We will take E as equal to $28 \times 10.^6$

For this stiffness of the spring, we have $EI/B_2 = 28 \times 10^6 \times .01318/607 = 610$ lbs. load per inch deflection. The safe load on the bottom plate will be $100000 \times .07032/11 = 639$ lbs. and the corresponding load at the end of plate No. 2 will be $639 \times 1.592 = 1017$ lbs.

It is now easy to calculate the stresses in every part of each leaf of the spring; this has been done, and the results are as shown in Fig. 28. It will be seen that the maximum stress in the tapered portion of plate No. 1 is almost exactly the same as the maximum stress at the central point of encastrèment, being, in fact, 103,000 against 100,000 lbs. per sq. in. For the longer or No. 2 plate it will be noticed that the maximum stress in the

FIG. 28.

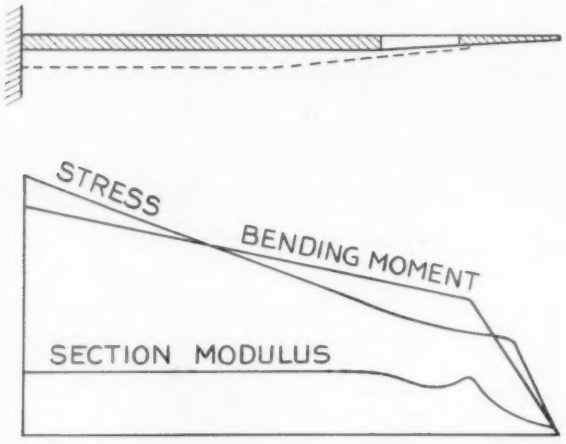


tapered portion is considerably greater, being 164,000 lbs. per sq. in., which of course is considerably too high. This indicates that the taper of the No. 2 plate is too fine and that the point should be made somewhat different in design, which should be of such proportions as to bring the stress in the tapered portion down to about the same value as that in the body of the plate. The stress at the central point of encastrèment is just about the same as for the No. 1 plate, being 102,000 lbs. per sq. in., so that, except for the somewhat fine taper at the end of the No. 2 plate,

this two-plate spring may then indeed be said to be of economical proportions with fairly uniform stresses all over.

An examination of Fig. 28 shows that near the ending of the uniform section of the plates and at the commencement of the tapers, the stresses are considerably lower than either in the body of the plates or in the tapered portions. This shows that it would be an advantage to remove some of the metal in these portions of the plates—for it is always better to keep the stresses everywhere as uniform as possible, so as to utilize the metal to the greatest possible advantage—and it has been found that by punching suitably shaped and properly placed holes in the position men-

FIG. 29.



tioned, the stresses are equalized to a great extent and the endurance of springs is increased: this has been thoroughly verified by many tests on the endurance machine and also by regular use of such springs on the road. These holes or slots are termed "stress equalizing slots" and form part of U. S. Patent No. 13,199,013, September 19, 1916. The effect is shown in diagrammatic form in Fig. 29, which figure is copied from that of the patent specifications.

As has already been stated, in most actual springs the plates separate on the application of the load, except at the ends and at the centre point of encastrèment. This may be verified by calculating the deflection of the plates at intermediate points by the use of the proper equations and noting the differences of such

deflections, of any two consecutive plates. The actual amount of separation is very small, to be sure, so that very accurate calculations are necessary in order to obtain concordant results.

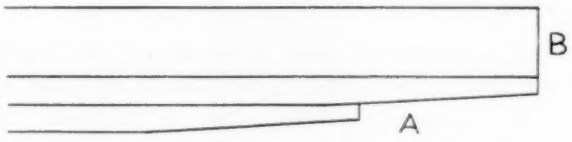
With the very flexible tapers which are sometimes used on the ends of the leaves, cases occur where the leaves tend to foul into one another. The effect of this is that instead of the leaves touching at the ends only, they have a contact for a distance depending on the flexibility of the tapered end. The only way to determine this is to calculate the deflections of the leaves at several points and compare the results. When this fouling tends to occur it shows that the tapers are too fine and instead of the reactions being at the tips of the leaves, they shift nearer to the centre of the spring, so that too fine a taper is equivalent to shortening the leaf. The calculations involving such "fine" tapers are complex, and seldom of commercial importance.

This completes the study of the reactions and stresses in the bodies of plate springs and there now remains only one more thing to be considered, in this paper, and that is the:

SEPARATION OF LOADS IN THE TOP COMPOUND PLATE.

It has previously been mentioned that when the "full length" plates are not tapered at all, they may, for primary purposes, be considered as equivalent to a single plate with a moment

Fig. 30.



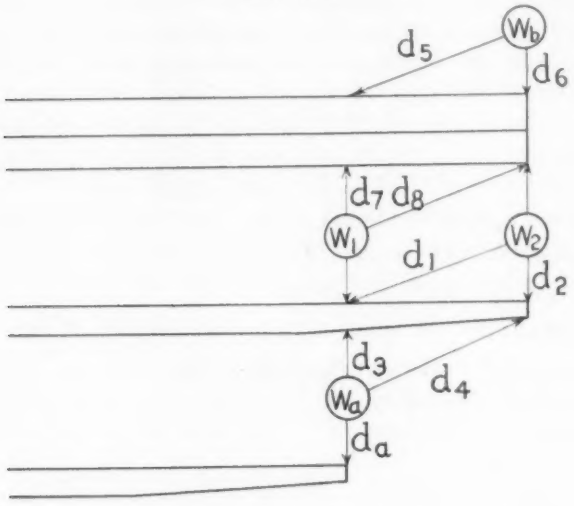
of inertia equal to the sum of the moments of inertia of the separate plates; then, after the final reaction has been found, it is evident that the various plates making the compound top plate will each support a portion of the load in direct proportion to its own moment of inertia. In this case, after finding the final load on the end of the spring, it is only necessary to divide this load in the ratios of the moments of inertia of the plates of the compound top plate, and the loads on the separate plates are at once determined. An example of this was given in our illustration for the No. 6 point.

In actual springs it will be found, however, that the lowest

of the long plates is generally tapered, and in this case a special investigation is necessary in order to separate the loads on the various plates, which have the same length.

The full length plates, including the main plate, which are not tapered, may be, for the primary calculation, considered as one plate with a moment of inertia equal to the sum of the moments of inertia of these plates, and the total load may after-

FIG. 31.



wards be divided between them in the direct ratio of their moments of inertia, in the same manner as before. We may therefore consider the compound top plate to be made up of one tapered and one plain end plate, as shown in Fig. 30.

The various deflection coefficients which will be required in the analysis are shown in Figs. 30 and 31, in which it is to be understood that for the tapered plate:

W_2 produces a deflection d_1 at A and d_2 at B

$W_a - W_1$ produces a deflection d_3 at A and d_4 at B;

for the plain plate or plates:

$W_b - W_2$ produces a deflection d_5 at A and d_6 at B

W_1 produces a deflection d_7 at A and d_8 at B

and for the spring W_b produces a deflection d_b at B.

A consideration of the deflections shows that:

$$\begin{aligned} d_1 - d_2 &= d_a \text{ (which is known)} \\ d_2 - d_4 &= d_b \\ d_5 - d_7 &= d_a \\ d_6 - d_8 &= d_b \end{aligned}$$

Now let $d_1 = k_1 W_2$, $d_2 = k_2 W_2$, $d_3 = k_3(W_a - W_1)$, $d_4 = k_4(W_a - W_1)$, $d_5 = k_5(W_b - W_2)$, $d_6 = k_6(W_b - W_2)$, $d_7 = k_7 W_1$, and $d_8 = k_8 W_1$: Then, inserting these values in the above equations and solving in the usual manner, it will be found that:

$$\frac{W_1}{W_2(k_1k_4k_5 - k_2k_3k_5) + d_a(k_1k_6 - k_2k_5)} = \frac{-W_2}{W_a(k_3k_6k_7 - k_3k_5k_8) + d_a(k_3k_6 + k_6k_7 - k_4k_5 - k_5k_8)}$$

$$= \frac{W_b}{W_a(k_1k_4k_7 + k_3k_5k_8 - k_2k_3k_7 - k_3k_6k_7) + d_a(k_4k_5 + k_5k_8 - k_2k_7 - k_6k_7)}$$

$$= \frac{-d_b}{W_a(k_1k_4k_5k_8 + k_2k_3k_6k_7 - k_1k_4k_6k_7 - k_2k_3k_5k_8) + d_a(k_2k_3k_6 + k_2k_6k_7 - k_1k_4k_6 - k_2k_5k_8)}$$

$$= \frac{1}{k_1k_4k_5 + k_1k_5k_8 - k_1k_6k_7 - k_2k_3k_5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (54)$$

which determines W_1, W_2, W_b and d_b.

The k's for use in the above equation are to be calculated in exactly the same manner as the A's of the earlier illustrations; there is no real difficulty, but there *is* a great amount of arithmetical work. The substitution of numerical values into the expressions given above offers no new features of interest, and there does not appear to be any necessity to give an example.

This concludes the analysis of reactions and stresses in plate springs as actually manufactured; the third paper will consider the internal stresses due to the "nip" produced in manufacturing and also the effect of the variation of the stresses on the life of a spring.

Meso-thorium as a Substitute for Radium. ANON. (Circular U. S. Bureau of Mines, December, 1918.)—The increasing demand for radium for medical work, but more particularly for luminous paint, has made the question of possible radium substitutes of considerable importance. Radium luminous paint has been used in the war for a number of purposes, more particularly on the dials of instruments used on airplanes, so that these instruments can be read at night; for electric push buttons, door numbers and small images for shrines, etc. The paint is permanently luminous in the dark and contains from 0.1 to 0.25 milligrams radium element to one gram of zinc sulphide. A luminous watch face usually has from ten cents' to twenty cents' worth of radium on it.

An excellent substitute for radium for certain purposes is meso-

thorium. This is a radio-active element found in monazite sand and other thorium minerals. When first extracted it is not in a satisfactory condition for luminous paint, but must be allowed to "ripen" for several months or even a year before it can be used. During this time the alpha radiation which is required for luminous paint becomes sufficiently strong. On the other hand, the beta and gamma radiation of meso-thorium grows rapidly and it can be used for medical purposes within a few days after preparation.

Radium has a long life, half of it decaying in approximately 1600 years. Meso-thorium, on the other hand, has a short life, 5 or 6 years being its useful life for luminous paint purposes. The price in the past has varied from 40 to 60 per cent. of that of radium, the comparison being on products of equal activity. For medical purposes, therefore, it cannot compete with radium as long as there is plenty of the latter; for luminous paint, to be used on objects which themselves have a short life, it is an excellent substitute for radium and will tend towards the saving of radium for medical purposes. It undoubtedly has been used during the war, especially by the Germans. Some of the first luminous watch dials in this country probably contained meso-thorium imported from Europe. Until recently no meso-thorium was recovered in the United States, although large quantities of monazite sand are annually treated for the manufacture of incandescent gas mantles. Such a condition has represented an important mineral waste.

Shortly after the United States entered the war the Bureau of Mines made a coöperative agreement with the Welsbach Company of Gloucester, N. J., for the study of methods of extraction and recovery of meso-thorium. The work was carried on at the Rocky Mountain station of the Bureau of Mines at Golden, Colo., under the direction of Dr. R. B. Moore, Superintendent of the station, Dr. Herman Schlundt being assigned to the detailed work on the problem. Successful methods of extraction and recovery have been worked out and connected up with the regular metallurgical processes of the Welsbach Company. Meso-thorium is now one of the regular products made by this company. The next largest producers of thorium salts in the country, about the same time became interested in the recovery of meso-thorium and worked out its own methods. Consequently at the present time meso-thorium is recovered from practically all the monazite sand treated in the United States.

The details of the work of the Bureau of Mines will be published later. A preliminary announcement was made by Dr. Moore in a paper given at the September meeting of the American Institute of Mining Engineers at Colorado Springs. Incorrect press reports of this announcement gave rise to some serious mis-statements of facts, hence this statement. The Bureau of Mines has never claimed the discovery of meso-thorium, as this element was first identified and described by Hahn in 1905.

THE RELATIVE MERITS OF CAST-IRON, WROUGHT-IRON AND STEEL PIPE FOR HOUSE DRAINAGE PURPOSES.*

BY

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AN investigation relating to the relative life, deterioration by corrosion, and other characteristics of pipe materials used in the main drainage, soil and vent system of buildings made during the past summer, should be of particular interest to sanitary engineers, progressive plumbers, health inspectors, superintendents and engineers of office buildings and to dealers in pipe materials.

I shall not go into the details of how the investigation was carried on, as these will appear at length elsewhere. But the actual findings and the conclusions reached therefrom are of much practical importance, and go far towards solving two, until now, mooted quesions, *viz.:*

(1) As to the superiority of cast-iron pipe and its caulked joint over welded pipe put together with screw joints.

(2) As to the comparative degree of corrosion of mild-steel and of genuine wrought-iron pipe.

My personal beliefs, derived from many years of practical experience, have long been:

(1) That screw-jointed drainage systems were better than cast-iron pipe systems, particularly for tall buildings.

(2) That genuine wrought-iron pipe was superior to steel pipe.

These opinions were unquestionably confirmed by the investigation.

Recent claims of cast-iron pipe manufacturers, however, that *both* steel and wrought iron were liable to considerable corrosion and quick decay, had rather startled me, so that I was glad of being offered an opportunity to investigate personally many of the assertions made.

The history of the development of house drainage systems is so well known to many readers of this paper that I shall not dwell upon it.

* Communicated by the Author.

This investigation, made in New York City, took in the principal buildings on both sides of Broadway, from Bowling Green (down-town) to Forty-second Street. Buildings less than 6 stories in height were omitted; we also passed by those erected less than five years ago, because they were not sufficiently old to give information of value as to the corrosion of pipes, for instance the Woolworth, Equitable Life, Adams Express, American Express Building and a few others.

The total number of buildings examined was seventy-eight, and distributed by age they ranged as follows:

Number of buildings over 30 years old	13
Number of buildings from 25 to 30 years old	10
Number of buildings from 20 to 25 years old	17
Number of buildings from 15 to 20 years old	17
Number of buildings from 10 to 15 years old	15
Number of buildings less than 10 years old	6
	78

Classified by pipe materials used, the buildings ranged as follows:

Number of buildings having cast-iron pipe systems	28
Number of buildings having black wrought-iron systems	1
Number of buildings having galvanized wrought-iron pipe systems	14
Number of buildings having black steel pipe systems	0
Number of buildings having galvanized steel pipe systems	12
Number of buildings having mixed wrought-iron and steel systems	23
	78

We noted carefully the age of each building and pipe installation, the number of floors, the pipe material used, the number of vent pipes on the roof, the number of samples taken from the vents and their condition, also the condition of the cellar drains. The names of the architect and of the plumbing contractor were also ascertained in many cases.

Cast-iron pipe systems were found in the oldest buildings, but in the later buildings preference seems to have been given to the screw-jointed system, both steel and wrought iron.

The roof vent pipes were selected as the principal objects of

the inspection and the tests, because they were almost the only parts of the house drainage system, the interior condition of which could be freely ascertained. Their condition and degree of corrosion, together with the age of the installation, gave important information regarding the life of the different pipe materials. Such actual service tests must be considered superior to so-called "accelerated" corrosion tests on small quantities of pipe.

Of the 1676 vents counted on the roofs of the seventy-eight buildings, one-third were cast iron and two-thirds were of welded screw-jointed pipe. Over five hundred samples of material from these vents were obtained for the chemical tests, which were made to determine whether the pipes were of steel or of wrought iron. These samples were all taken and subsequently analyzed under my personal direction, so that no doubt was left as to the correctness and accuracy of the tests.

Inasmuch as the conclusions reached are based chiefly—though not entirely—upon the tests made, it will be well to describe these fully. The question as to whether a pipe is of wrought iron or of steel is one against which engineers and plumbers frequently run, and it would be well if they kept themselves better informed, so as to know how to go about it to determine whether a pipe is of steel or of wrought iron. This knowledge, as will be seen, can readily be acquired, and should really form part of the "stock in trade" of every progressive plumber.

There are in use six principal tests, three of which are mechanical, two chemical and one microscopical. What test to use depends upon whether a large sample ring of a pipe can be obtained, or whether only chips or filings can be taken, as is the case when pipes are already installed and cannot be removed.

I. FRACTURE TEST.

If a piece of pipe is available, the crushing or fracture test can be made by any person; it is likewise the surest in its indications. Fig. 1 shows a piece of genuine wrought-iron pipe hammered flat to the point of fracture. The surface of the fracture appears ragged, dull gray and fibrous. Fig. 2 shows a piece of steel pipe, which after similar treatment presents an even, bright and crystalline fracture.

In connection with the fracture test it is interesting to note that when the pipe to be tested is galvanized, the galvanized coating

does not scale or chip off if the pipe is wrought iron; it sticks to it and breaks with the iron without cracking (see Fig. 1). If, on the other hand, the pipe is of steel, the fracture test causes the galvanizing to peel off in scales or flakes, and this occurs almost at the first stroke of the hammer (see Fig. 2). These

FIG. 1.

Galvanized iron pipe.

FIG. 2.

Galvanized steel pipe.

cuts, Figs. 1 and 2, are from a recent Bulletin, No. 41, May, 1918, of the A. M. Byers Co., in Pittsburgh.

II. THREADING TEST.

Another mechanical method of testing consists in cutting a thread on the pipe. A wrought-iron pipe, when being threaded,

has the chips breaking and crumbling, whereas in a steel pipe the chip tends to curl and form a long spiral, which is apt to clog the die space during the threading.

III. CORROSION TEST.

This is in reality not a test, but merely the observation of the characteristic appearance of rusting. It is, of course, restricted to pipes which have been in use for many years and which have begun to show the effects of corrosion. Speaking only from the observations made by me in the New York investigation, the fact became apparent that wrought-iron and steel pipes showed two very distinct forms of rusting. The wrought-iron pipes show "pitting" or became "pockmarked," while steel pipes "scale" and flake off.

Fig. 3 shows some black wrought-iron vent pipes, in use twenty-seven years, photographed on the roof of the Mail and Express Building, cor. Fulton and Broadway, while Fig. 4 shows steel vent pipes in use twenty-three years, photographed on the roof of the Townsend Building, No. 1123 Broadway. The different ways in which the two pipe materials corrode is quite apparent from the illustrations. Fig. 5 shows how cast-iron vent pipes corrode; they show a nearly uniform pitting, not unlike that of genuine wrought-iron pipes.

IV. THE ACID OR CHEMICAL TEST.

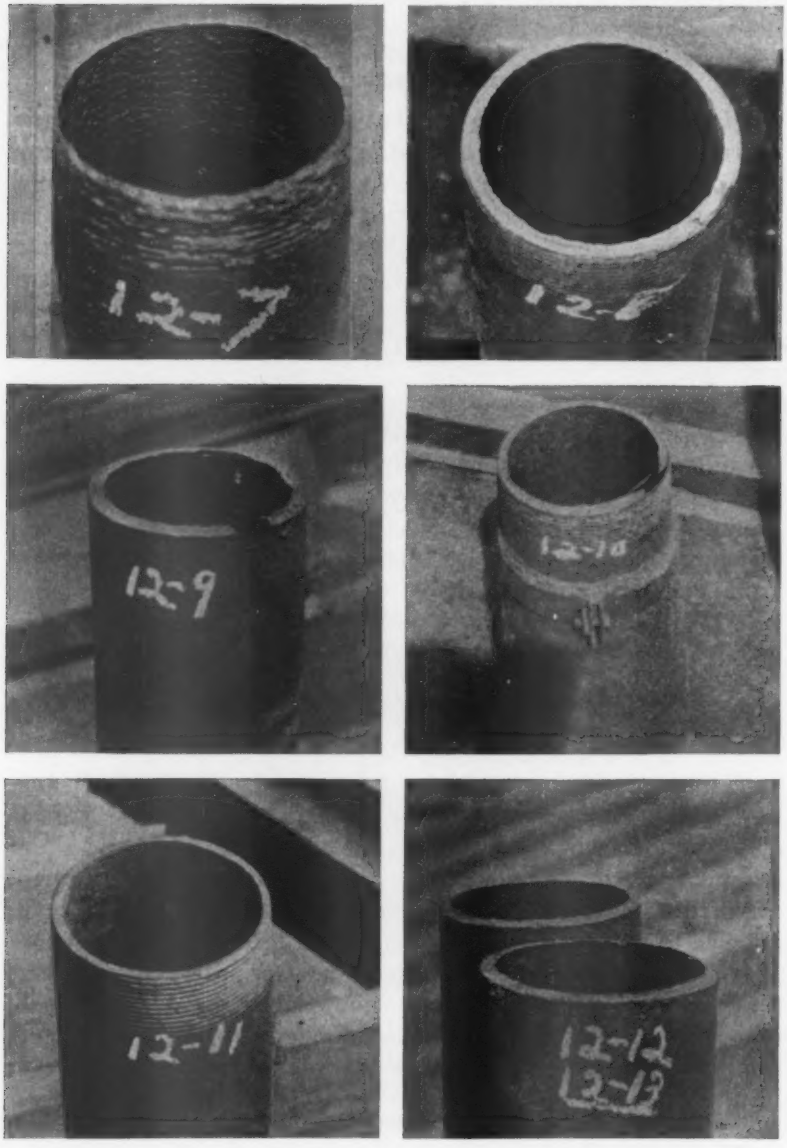
(See *Iron Age*, Dec. 23, 1909.)

To distinguish between wrought iron and soft steel the sample of pipe is cleaned from grease and scale and then immersed in a solution of 9 parts of water, 3 parts of sulphuric acid and 1 part of muriatic acid. The acids are poured into the water, and the mixture is allowed to cool. The pipe material to be tested is allowed to remain in the solution from fifteen to twenty minutes. It is then taken out and rinsed in clear water. The characteristic fibres of wrought iron will now show plainly, but if they should not do so the process is continued longer. Soft steel dissolves uniformly and without the fibrous structure found in wrought iron.

V. THE MANGANESE TEST.

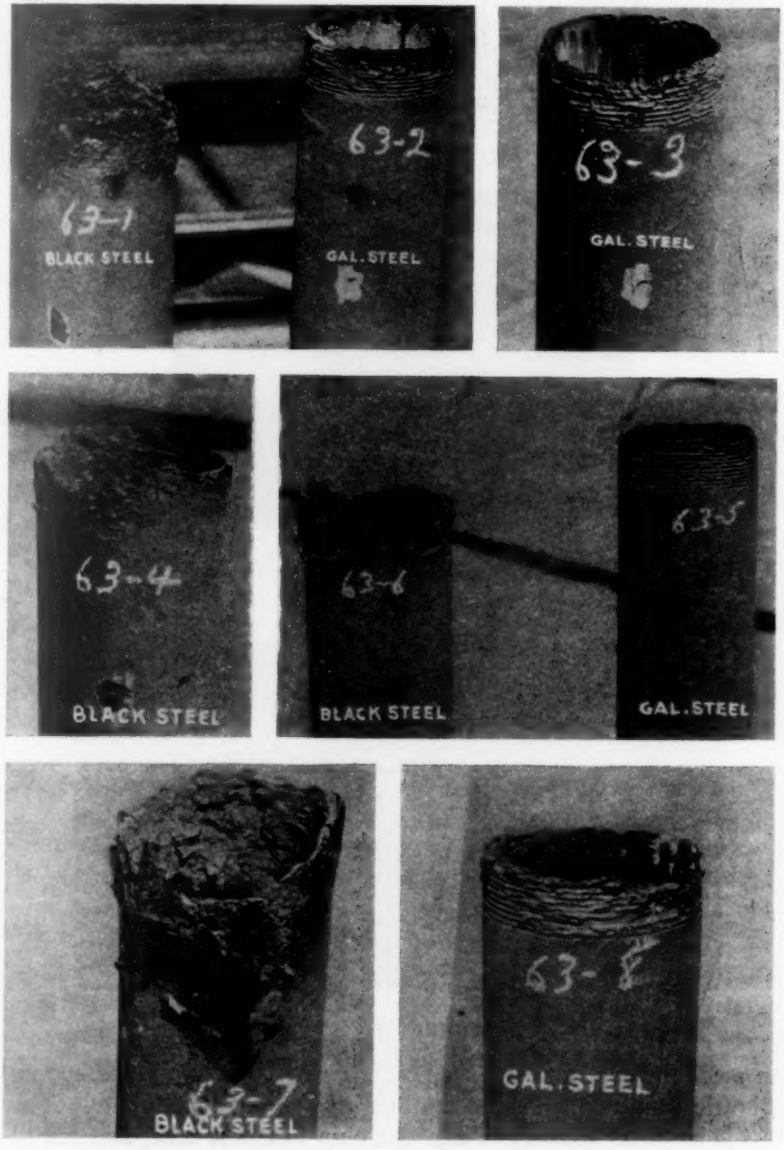
This test is an exceedingly simple chemical test and one which is particularly useful when the pipe to be tested is installed and

FIG. 3.



Wrought-iron vent pipes on roofs of Mail and Express Building after 27 years' service.

FIG. 4.



Steel vent pipes on roof of Townsend Building after 22 years' service.

cannot be removed. The test can be readily performed by any one having the necessary testing outfit, which is shown in Fig. 6.

Small filings or chips from the pipe are obtained and enclosed in an envelope, marked for identification. The testing outfit illustrated consists of some glass test tubes in a wooden rack,

FIG. 5.

Characteristic pitting of cast iron.

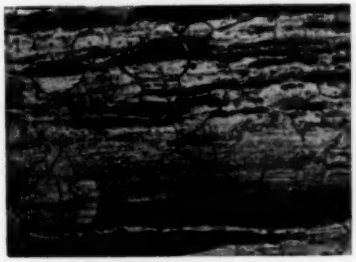
FIG. 6.

Manganese testing outfit.

an alcohol lamp, a pair of pincers, a small glass ladle or spoon, a bottle of nitric acid and another of sodium bismuthate. The test is made as follows: Place one chip in a test tube, add ten to fifteen drops of chemically pure nitric acid, diluted with equal parts of water, and hold the tube over the alcohol flame until

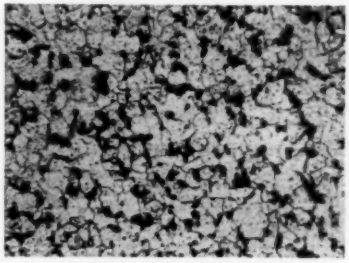
the metal becomes dissolved. Place the tube back in the rack and allow it to cool, then add a small quantity of the sodium bismuthate, enough to produce a brown residue or deposit. The solution now gives off bubbles of oxygen and then it develops a pinkish or red color, which indicates the presence of manganese, and that the pipe sample is of steel. If no reddish tint appears, but only a brown deposit in the bottom of the test tube, the sample is of wrought iron.

FIG. 7.



Micro-section of wrought iron, taken parallel to rolling.

FIG. 8.



Micro-section of soft steel.

This test is based upon the fact that in the manufacture of steel pipe ferro-manganese is added to the hot metal in the Bessemer retort to enable the rolling and welding of the steel, whereas no manganese whatever is added in the puddling process for wrought iron.

It does occasionally happen that wrought iron contains more

than a trace of manganese, in which case the indications of the manganese chemical test are not to be taken without further investigation. It becomes advisable, under such conditions, to make a fracture test, or else to get a large sample of the pipe and to have its structure examined microscopically.

In my New York investigation both the managanese and the fracture tests were made, and in doubtful cases samples were referred by me to Prof. W. Campbell and to Dr. Fales, of Columbia University for a decision.

VI. THE MICROSCOPIC TEST.

This test can be made only in a physical laboratory, but it is the most decisive test of those mentioned. The sample of pipe is polished and then etched with picric acid. If it be genuine wrought iron, the metal will show the characteristic silicate slag fibres in the longitudinal section (see Fig. 7); if of steel, no slag fibres will appear, but instead the sample tested shows an even distribution of pearlite (see Fig. 8).

These are the various tests with which the writer became acquainted, though there may be others known to chemists or metallurgists.

Both steel and wrought-iron pipes, if made and sold in the past five years, can be identified by looking at the roll marks. All the largest manufacturers of welded pipe have adopted this means of having their pipe recognized by names, such as "Reading," "Byers" or "National," rolled in large letters on the outside of the pipes. If the year of manufacture is likewise rolled in, as is done by the Byers Company, this will serve in future observations or investigations to determine the length of time the pipe has been in service.

SUMMARY OF CONCLUSIONS.

The results of this investigation will be given in full in the Transactions of the American Society of Mechanical Engineers for 1917. They were likewise presented by the author at the annual meeting, on December 6th, in New York City, of the Society, and may be had in pamphlet form. They may be summarized briefly as follows:

1. Extra heavy cast-iron soil-pipe is a satisfactory material from the corrosion point of view. It is unsatisfactory as regards

the calked joints. These become affected by changes in temperature, and do not remain tight under all conditions of service.

2. The screw joint of welded pipe is superior to the calked joint, provided the threads are so cut, and the recessed drainage fittings so tapped that the pipe can be screwed well into the shoulder of the fitting. Portions of the thread remaining exposed to view should be protected against external corrosion.

3. The evidence furnished by the investigation leaves no doubt as to *genuine wrought-iron pipe being a far more durable material* for house drainage purposes *than steel pipe*.

A careful examination of the illustrations, Figs. 3 and 4, will confirm this statement. Compare the twenty-two-year-old steel pipe installation in the Townsend Building with the twenty-seven-year-old installation in the Mail and Express Building. These are only two examples out of many collected and on file.

In conclusion, I ought perhaps to state that I entered into this investigation without bias or prejudice. The results obtained should be of interest to architects and builders, consulting engineers, plumbing contractors and managers of large buildings or institutions.

New Method of Cooling Gas Engines. ANON. (*Power Plant Engineering*, vol. 22, No. 20, p. 849, October 15, 1918.)—External water-cooling is the cause of many of the disadvantages in the use of the gas engine which have retarded its development in large sizes. Experiments conducted by Professor Hopkinson of Cambridge, England, have demonstrated that the difficulties incident to jacket-cooling can be overcome by cooling the cylinder from the inside by means of water jets. When the cylinder is thus cooled, there is no heat-flow through the metal and the stresses due to unequal heating are avoided. In this method of internal cooling, cold water is injected through a hollow casing projecting into the combustion chamber and provided with a number of holes or small nozzles about 1/32 inch in diameter. The jets are directed to all parts of the surface of the combustion chamber and against the face of the piston.

Difficulties of corrosion and lubrication are overcome by regulating the quantity of water in such a way that the temperature of the cylinder is kept well above 100° C. For practical purposes,

the heat-flow during the last three-fourths of the stroke is so small that direct cooling of that portion of the cylinder can be dispensed with, and it is sufficient to cool the surfaces of the combustion chamber and head of the piston only. A simple single-walled casting can be used for the cylinder, resulting in a great saving in weight and cost and in improved reliability by the elimination of casting stresses. Arrangements for cooling the piston, which are necessary in large engines, may be omitted. Finally, pre-ignitions are entirely prevented.

Water Power as a National Asset. ANON. (*Electrical World,* vol. 72, No. 28, p. 1209, December 28, 1918.)—Canada can teach us much regarding the conservation of natural resources. Her water-power sites are not only surveyed; their economic features, capacities and in many instances costs of development are known as well. Moreover, in seeking to have these resources used, the Dominion government, while it affords reasonable protection to the public, at the same time offers suitable financial reward to private enterprises. There is, however, little advantage for Canada to develop power which is transmitted to the United States, especially when there is a shortage of power in the Dominion. Many Canadians are, therefore, solicitous about her natural resources and insist that her water powers should be developed for her people. Hence the growth of immense systems like that of the Hydro-Electric Power Commission of Ontario. Inasmuch as the greater part of the population of the Dominion of Canada dwells along the St. Lawrence River valley and it is in the provinces of Quebec and Ontario that the greatest amounts of power are developed and used, the utilization of the waters of the St. Lawrence for power purposes is of immense interest to Canadians. There are no indications that the Canadians object to the joint development of the river by the Dominion and the United States or by the two provinces mentioned and the State of New York. But Canadians have a very firm conviction that none of the water should be used for private enterprises. The water may be used by local, state and national governments or by creations of those governments in the shape of public utility corporations amenable to rules and regulations of the respective states as to rates, service, etc., through commissions. A similar public opinion regarding water powers is beginning to crystallize in this country.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A PORTABLE CUBIC-FOOT STANDARD FOR GAS.[1]

By M. H. Stillman.

[ABSTRACT.]

THIS paper describes a new type of volume standard for measuring gas, which has been found to possess decided advantages as a cubic-foot standard over the apparatus of this class largely in use at the present time.

While especially well adapted to that class of work in which an inspector is required to make tests of gas-meter testing equipment distributed over a comparatively large territory, it has also been successfully used for other purposes in which the delivery of a comparatively small volume of gas with a high degree of accuracy is required.

The device is essentially a miniature meter prover, radically modified to secure accuracy and rapidity in operation and compactness in construction.

An auxiliary meter-prover scale, the use of which contributes to the accurate and convenient calibration of meter provers, is also described.

MANUAL OF INSPECTION AND INFORMATION FOR WEIGHTS AND MEASURES OFFICIALS.[2]

By F. S. Holbrook.

[ABSTRACT.]

THIS manual is designed primarily for official sealers and inspectors appointed to enforce weights and measures laws or ordinances, but it will also be of use to any one who has occasion to inspect and test weights and measures and weighing and measuring devices of the types ordinarily found in commercial use. It contains specifications and tolerances and complete instructions for the testing of all kinds of scales, length measures, liquid and dry capacity measures, etc.; general instructions concerning

* Communicated by the Director.

[1] Technologic Papers No. 114.

[2] Miscellaneous Paper No. 1.

the enforcement of law; lists of standards and apparatus; a method of keeping office records, etc. Appendixes are included containing Federal weights and measures laws, with rules and regulations, the model State law in relation to weights and measures, a description of the metric system and general tables, conversion table and tables of equivalents.

PRELIMINARY DETERMINATION OF THE THERMAL EXPANSION OF MOLYBDENUM.[3]

By Lloyd W. Schad and Peter Hidnert.

[ABSTRACT.]

THE thermal expansion of an exceptionally pure specimen of molybdenum was determined from $-142°$ to $+305°$ C.

A short description of the apparatus and of the method used in obtaining high and low temperatures is given.

The results are shown in the form of tables, from which were computed by the method of least squares, the two following empirical equations which satisfy the observations:

$$L_t = L_o\,(1 + 5.15\,t \times 10^{-6} + 0.00570\,t^2 \times 10^{-6})$$

and

$$L_t = L_o\,(1 + 5.01\,t \times 10^{-6} + 0.00138\,t^2 \times 10^{-6})$$

where L_t is the length of the specimen at any temperature t within the proper range; in the first case $19°$ to $-142°$ C., and in the second case $19°$ to $+305°$ C. The probable error of the length computed from these equations is less than 3×10^{-6} per unit length.

THE DECREASE IN ULTRA-VIOLET AND TOTAL RADIATION WITH USAGE OF QUARTZ MERCURY VAPOR LAMPS.[4]

By W. W. Coblentz, M. B. Long, and H. Kahler.

[ABSTRACT.]

THE object of this present investigation was: (1) To devise methods of determining quantitatively the decrease in intensity of emission with usage and (2) to make preliminery measurements on radiant-power life-tests of quartz mercury vapor lamps.

[3] Scientific Paper No. 332.
[4] Scientific Paper No. 330.

The measurements of the radiations from these lamps were made by means of a thermopile, in front of which was placed a 1-cm. cell of water, to absorb the infra-red rays of long wave-lengths emitted by the electrodes.

The variation in intensity of the ultra-violet rays was determined by observing the variation in transmission of a yellow, Noviol glass, with usage of the lamp.

It was found that the intensity of the total radiation, as well as the ultra-violet component, decreased to about ½ to ⅓ of its initial value in the course of 1000 to 1500 hours.

During the first 500 hours' usage no marked difference was observed in the per cent. of ultra-violet emitted by the two types (Cooper Hewitt and R. U. V. Co.) of lamps.

Data are given (1) on the variation of the total radiation emitted by quartz mercury vapor lamps with variation in energy input, (2) on the variation of the intensity of the irradiation parallel with the axis of the lamps and (3) on the variation of the intensity of the total radiation with distance from the lamps.

Comparative data are given on the ultra-violent component in the radiations from the sun, from quartz mercury vapor lamps, and also from a carbon arc lamp which is used in dye-fading tests.

MEASUREMENTS OF WAVE-LENGTHS IN THE SPECTRUM OF NEON.[5]

By Kelvin Burns, W. F. Meggers, and P. W. Merrill.

[ABSTRACT.]

THE lines in the neon spectrum are very sharp, a quality which recommends this gas as a standard source wherever the lines have sufficient strength. The ultra-violet group between 3369A and 3520A may be used for standards, and there are a few good infra-red lines, but the strength and distribution of the lines in the region 5852A to 7438A make the neon spectrum particularly useful as a comparison in this region.

The wave-lengths of fifty-five lines in the neon spectrum have been measured by means of the interferometer. These lines lie in the region 3369A to 8495A. The strong lines in the visible region of the spectrum have been observed with great accuracy.

[5] Scientific Paper No. 329.

the probable error being one part in several millions, or less than one-tenth the width of the line. These strong lines were observed by means of three different pairs of interferometer plates, which were each used on several interferometers. The ultra-violet lines and all the strong lines in the visible were compared directly with the fundamental standard 6438A. Some of the deep red and infra-red lines were compared with well-determined lines in the visible neon spectrum.

One hundred and eighty-nine faint lines in the visible and infra-red neon spectrum have been measured by means of a concave grating. The probable error of these grating measurements is one or two hundredths angstrom. The region covered by the grating observations extends from 5343A to 8783A.

The constant differences discovered by Watson are found to hold with remarkable exactness in the case of lines which are strong enough to be measured with the highest accuracy. In fact, the differences are exactly constant within the limits set by the accuracy of the wave-lengths.

A Target Practice Airplane. ANON. (*Scientific American*, vol. 129, No. 26, p. 511, December 28, 1918.)—An American aircraft builder has introduced a diminutive airplane which flies itself without the aid of any human hand to guide it, and can therefore be used as a target, thus bringing realism and efficiency to the aerial gunnery schools. The airplane is of the Burgess-Dunne type, modified to meet the conditions for which it was designed. Inherent stability is obtained by employing a large sweepback and negative dihedral angle. The course of the machine is governed by setting and locking the control surfaces in position prior to flight.

The little machine is of the seaplane design to facilitate starting and alighting. It has a span of 18 feet 5 inches with a cord of 28 inches. The length is 9 feet, while the overall height is 4 feet 8 inches. Although the weight of the complete machine is only 175 pounds, it is capable of carrying a man. The power plant consists of a 12-horsepower four-cylinder motorcycle engine which has been rebuilt to meet the special requirements. The propeller is 42 inches in diameter, mounted as a "pusher." While climbing the diminutive airplane develops a speed of 40 miles per hour, which rises to 50 when flying on a level keel.

NOTES FROM THE INSTITUTE OF INDUSTRIAL RESEARCH.*

LIEUTENANT-COLONEL ALLERTON S. CUSHMAN, Ordnance Department, U. S. A., has just received his honorable discharge from the Army. For eighteen months he had charge of the research and chemical laboratories, including the explosive activities, at Frankford Arsenal, Pennsylvania, where he was engaged principally on ammunition and metallurgical problems. He now returns to his former professional activities as head of this private research institution, where his services, as well as those of the entire personnel and the laboratory facilities, will be at the disposal of clients.

The other members of the Institute staff have also resigned from various branches of war service in which they were engaged. Former Lieut. Henry A. Gardner, U. S. N., is a distinguished expert on paints, varnishes, etc.

Dr. George W. Coggeshall, chemical engineer with the Emergency Fleet Corporation, is expert on concrete, waterproofing, plant design and extension and general chemical engineering problems. Dr. Coggeshall specialized during the war on concrete ship construction, including oil-proofing and water-proofing.

Mr. H. C. Fuller, who is well known in pharmaceutical and food problems, takes up again the control of the food and drug laboratories of this Institute.

All these gentlemen return from their war service work, to which they made valuable contributions and in which they gained added knowledge and experience, with a very strong belief that this country has before it a great industrial future. The value of the service of chemistry and chemical engineering has been so definitely proved during the war that it seems certain that our manufacturers will turn naturally for expert and scientific work to institutions of a nature similar to our own.

* Communicated by the Director.

The Ferro-Alloys. J. W. RICHARDS. (*General Electric Review*, vol. 21, No. 11, p. 751, November, 1918.)—A large industry has grown up within the last fifty years, most of it within the last twenty-five years, which furnishes steel makers alloys of iron with some of the rarer metals. It is quite commonly known that the addition of these metals to steel greatly improves its qualities for special purposes. These ferro-alloys were originally made in crucibles, cupolas or blast furnaces, but are now made principally in electric furnaces and their manufacture is now one of the principal electric furnace industries. They are of great importance to the steel industry. The steel maker uses them for one of two purposes: (1) As reagents to take oxygen out of melted steel and thus insure sound, solid casting. For this purpose, ferromanganese, ferrosilicon, and ferroaluminum are employed. (2) To add to the steel a small or large percentage of the rare metals, ferromanganese, ferrochromium, ferrotungsten, ferromolybdenum, ferrovanadium, ferrotitanium, ferrouranium, ferroboron.

Melted steel, just before it is taken from the furnace, always contains some dissolved oxygen (like the dissolved gas in charged soda water). The addition of a small amount of metal with a high affinity for oxygen removes this element and makes the casting sound. Manganese (1 per cent. or less) is the cheapest and most generally used reagent; silicon (½ per cent. or less) is more powerful but also more expensive, and is often used to supplement the action of the manganese; aluminum (0.1 per cent. or less) is still more powerful and expensive, and is used in very small quantities as a final addition to complete the action of the manganese and silicon. All steel makers use one, two, or all three of these reagents; manganese and silicon in the form of ferro-alloys; aluminum more often as the pure metal, though ferroaluminum is sometimes used.

When a sufficient quantity of the rare metal is added to the steel, it acquires properties different from plain carbon steels deoxidized by manganese, silicon, or aluminum. Thus, a very tough, hard steel, such as is used in mining and grinding, burglar-proof vaults, etc., may be made by the addition of 12 to 14 per cent. of manganese. Chromium (2 to 4 per cent.) makes a very hard tool steel; tungsten (15 to 25 per cent.) makes a high-speed tool steel which, while red hot, cuts iron. Vanadium (0.1 to 0.5 per cent.) makes a very strong steel which resists shock extremely well, as when used for automobile axles; titanium, uranium and boron also impart valuable properties. Every one of these materials produces some specific result; sometimes two, three or four are used for producing a specific combination of special properties. Some of these materials cost $5 per pound, and the special steels produced cost up to $2.50 per pound, but their particularly valuable properties justify the expense.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting Held Wednesday, December 18, 1918.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 18, 1918.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 4.

Reports of progress were presented from the Committee on Library, and the Committee on Science and the Arts.

The following nominations were made for officers and managers to be voted for at the annual election to be held on January 15, 1919:

For President (to serve one year), Walton Clark.

For Vice-President (to serve three years), Henry Howson.

For Treasurer (to serve one year), Cyrus Borgner.

For Managers (to serve three years), Francis T. Chambers, W. C. L. Eglin, Alfred C. Harrison, Nathan Hayward, Charles A. Hexamer, Robert W. Lesley, Marshall S. Morgan, E. H. Sanborn.

The paper of the evening, entitled "Vehicular Tunnels Under the Hudson River," was presented by Mr. Martin Schreiber, Member American Society of Civil Engineers, Chief Engineer, Public Service Railway Company, Newark, N. J. A general outline was given of the traffic conditions at the port of New York as far as they affect the necessity for vehicular tunnels under the Hudson, or North River. Descriptions were given of the various official bridge and tunnel plans thus far proposed. The important engineering phases were discussed, especially those relating to the ventilation of tunnels. The paper concluded with a résumé of the present status of the project. In the discussion which followed the paper Messrs. Alleman, Chance, Crisfield, Lindenthal, Modjeski, the Chairman, and others participated.

After a vote of thanks to the speaker, the meeting adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

MEMBERS OF THE FRANKLIN INSTITUTE WHO ARE IN THE ACTIVE MILITARY OR NAVAL SERVICE OF THE UNITED STATES GOVERNMENT.

Name and rank	Branch of service	Location
Allen, Henry B., Captain	Ordnance Dept., N. A.	France
Amram, Philip W., 2nd Lieut.	Student Army Training Corps	Harvard Univ.
Anderson, Geo. L., Colonel	Board of Ordnance & Fortification	Washington
Atherholt, Gordon Meade	Aeronautical Mechanical Engineer, Signal Corps	Washington
Atterbury, W. W., Brig. Gen.	Director-General of Railways	France
Bacon, Raymond Foss, Lt. Col.	Head of Chemical Service Section, U.S.N.A.	France
Barnhart, G. Edw.	Aeronautical Mechanical Engineer, Signal Corps	Fairfield, Ohio
Barr, John H., Major	Ordnance Reserve Corps	Washington
Barrett, C. D., Major	9th Engineers	
Bartow, Edward, Major	U.S.N.A. Sanitary Corps	France
Billings, A. W. K., Lieut. Com.	Chief Engineer, U. S Naval Forces (Aviation)	London
Booz, Horace Corey, Colonel	Railroad Transportation Corps, U.S.N.A.	France
Bostwick, John Vaughan, Capt.	O.R.C., 315th Infantry	
Breed, George, Lieutenant	Fleet Naval Reserve, U.S.N. R.F.	New York
Brown, Lucius P., Captain	Sanitary Corps, Division of Food and Nutrition	Camp Greenleaf
Bunting, C. M., Colonel	E.O.R.C., U.S.A.	France
Cadwalader, Governeur, Major	Ordnance Dept., U.S.R.	
Caldwell, E. W.	Medical Officers' Reserve Corps	
Capps, W. L., Rear Admiral	Chief Constructor, U.S.N., Bureau of Construction and Repair	Washington
Carty, John J., Colonel	Signal Corps, U.S.A.	
Cathcart, Wm. L., Lieut. Com.	U. S. N. R. F.	Washington
Chance, Edwin M., Capt.	Ordnance Dept., U.S.R.	Washington
Clark, Beauvais, Sergeant	108th Field Artillery	France
Clark, E. B., Major	Gas and Flame Service, A.E.F.	France
Clark, E. L., 1st Lieut.	Signal Corps, 401st Telegraph Battalion	Camp Devens
Clark, Theobald F., Capt.	Field Artillery	France
Clark, Walton, Jr., Capt.	Field Artillery	France
Coates, Jesse, Major	American Expeditionary Force Air Service, U .S. A.	France
Cope, Thomas D., Captain		Langley Field
Cornelius, John C., 1st Lieut.	Coast Artillery, U.S.N.A., 13th Company	Sandy Hook
Cottrell, Jas. W., Sergeant	Instructor Ordnance Motor Instruction School	Metuchen, N. J.
Cowan, Henry B., Sergeant, 1st Class	Co. D., First Telegraph Battalion, Signal Reserve Corps	France
Crampton, George S., Major	Director of Field Hospitals, 28th Div., A.E.F.	France
Cushman, A. S., Lieut. Col.	Ordnance Dept., U.S.N.A.	Frankford Arsenal
Detwiler, Jas. G., 1st Lieut.	Infantry, U.S.R.	Fort Logan H. Roots
Douredoure, Bernard L.	Signal Service Officers' Training Camp	Camp Meade

Name and rank	Branch of service	Location
Eckert, S. B., Lieut.	Commander 9th Aero Squadron	France
Edwards, JohnR., Rear Admiral	Brown University	Providence, R.I.
Elliot, A. H.	Engineers Reserve Corps	Philadelphia
Elliott, Henry M., 1st Lieut.	Ordnance Dept., U.S.R.	Western Cartridge Co.
Emerson, Geo. H., Colonel	In charge of Russian Railway Service Corps	Japan
Felton, Samuel M.	U. S. Director-General of Railways in connection with Expeditionary Force	Chicago
Ferguson, Walter B., Sergeant	21st Co., 154th Depot Brigade	Camp Meade
Fraser, Persifor, Ensign	U.S.N.R.F.	League Island
Gardner, H. A., Senior Lieut.	Naval Flying Corps	Washington
Gfrörer, A. H., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Gibbons, Joseph E., Private	Co. D., 103rd Engineers	France
Gilbreth, Frank B., Major	Engineers O. R. C.	Washington
Gillmor, R. E., Senior Lieut.	U. S. Navy	New York
Glendinning, Robt. E., Major	Aviation Section, Signal Corps	Overseas
Gomberg, M., Major	Ordnance Reserve Corps	Washington
Goodwin, Harold, Jr., Lieut.	Naval Reserve Force	Philadelphia
Gribbel, W. G., Captain	Co. A., 30th Engineers, U.S.R. (Gas and Flame)	France
Griest, Thos. S., 1st Lieut.	1st Telegraph Battalion, Signal Corps, U.S.A.	France
Hall, R. T., Rear Admiral	U. S. Navy, Inspector of Machinery	Cramps' Shipyard
Hammer, William J., Major	Inventions Section, War Plans Division, General Staff, War College	Washington
Hodges, Austin L., Capt.	Ordnance Dept., U.S.R., Experimental Officer on Artillery Ammunition	Frankford Arsenal
Howson, Richard, 2nd Lieut.	Field Artillery	Camp Zachary Taylor
Ives, H. E., Captain	Signal Corps, U.S.A.	Washington
Jackson, John Price, Major		France
Jones, Jonathan, Captain	E.O.R.C., 23rd Engineers	Camp Laurel
Junkersfeld, P. Major	E. O. R. C.	Washington
Karrer, Enoch, Senior Master Engineer	488th Engineers	Washington
Kennedy, M. C., Colonel	Deputy Director General of Transportation	France
Kent, S. Leonard, Jr., 2nd Lieut.	5th Engineers	Camp Lee
Kingsbury, E. F., Captain	Air Service Dept. of Science and Research	Washington
LeBoutillier, H. W., Private	Unit No. 10, Pennsylvania Hospital	France
Lenher, Victor, Major	Chemical Warfare Service, N.A.	Madison, Wis.
Lichtenberg, Chester, 1st Lieut.	Engineer Reserve Corps, U.S.A.	Washington
Lippincott, Joseph Wharton, Yeoman, 1st class	U. S. Naval Reserves	Washington
Littleton, Wm. Richards	Assistant Paymaster, U. S. N.	Philadelphia
Longstreth, Chas., Lt. Commander	U.S.N.R.F.	New Castle, Del.
Lucke, Charles E., Lt. Commander	U.S. Navy Gas Engine School	New York City, New York
McCoy, John F.	Aviation Section, Signal Corps	Princeton
MacLean, Malcolm R., Major	Infantry R. C.	Camp Meade
McMeekin, C. W., Major	Army War College	Washington

Name and rank	Branch of service	Location
Martin, Thos. S., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Masters, Frank M., Major	Ordnance Dept., U.S.R.	Washington
Maxfield, H. H., Lieut. Col.	19th Railway Engineers, U.S.N.A.	
Mershon, Ralph D., Major	E.O.R.C., U.S.A.	New York
Miller, Casper W., Major	Medical Corps Division of Food and Nutrition	Washington
Miller, Fred. J., Major	Ordnance Reserve Corps	Centre Bridge, Penna.
Owens, R. B., Major	Chief Signal Officer, Base Section No. 3, A.E.F.	London
Parrish, T. R., Captain	Signal Corps	Washington
Pemberton, Henry R.	U. S. Naval Air Service	Key West, Fla.
Reber, Samuel, Colonel	Signal Corps, U.S.A.	New York
Richardson, Chas. E., 1st Lieut.	30th Engineers, U.S.R. (Gas and Flame)	France
Sessler, Grover C.	Assistant Civil Engineer, U. S. N. R. F.	Philadelphia
Spackman, Henry S., Lieut. Col.	Engineer Officers' Reserve Corps	France
Spruance, W. C., Jr., Lt. Col.	Ordnance Dept., National Army	Chevy Chase. Md.
Squier, Geo. O., Major General	Chief Signal Officer, U.S.A.	
Stanford, H. R., Captain	U. S. Navy	Boston
Synnestvedt, Arthur	Development Battalion	Camp Greenleaf
Thomas, Geo. C., Jr., Captain	Aero Service Squadron 96, Aviation Section, Signal Corps	France
Tilghman, B. C., Captain	A.D.C., 28th Div. Headquarters, U.S.A.	
Ulmer, Carl D., Private	Chemical Warfare Service, A.E.F.	France
Vogleson, J. A., Major	Sanitray Corps	Camp Jas. E. Johnston
Wagner, Fred. H., Major	Ordnance Reserve Corps, Nitrate Division	Washington
Wagner, Fred. H., Jr., Sergeant	Co. E., 304th Engineers	Camp Meade
Wells, G. A., Captain	Ordnance Reserve Corps	Peoria, Ill.
Wetherill, W. C., Ensign	U. S. Navy	
Weyl, Charles N.,	U.S.N.R.F.	Philadelphia
Widdicombe, R. A., Major	C.Q.M., Chemical Plant No. 4	Saltville, Va.
Wood, Edw. R., Jr., Captain	18th Field Artillery, U.S.N.A.	France
Worrell, Howard Sellers	3rd Officers' Training Camp	Fortress Monroe
Wyckoff, A. B., Lieut.	U. S. Navy	Ontario, Cal.
Yale, A. W. Major	Railway Artillery Reserves	France
Yorke, George M., Major	Signal Corps, U.S.R.	New York

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Balls, William H.	Ships Draughtsman	Phila. Navy Yard
Bancroft, Joseph	Secretary, Local Board No. 1	Wilmington
Baskerville, Charles	Working with Bureau of Mines, Ordnance Dept. (Gas Warfare, Shells, etc.)	New York

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Condict, G. Herbert	Naval Consulting Board, Member Committee of Examiners	Plainfield, N. J.
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Day, Charles	Member of Army War Council	Washington
Delano, Frederic A.	Member of Federal Reserve Board	Washington
Dunn, Gano	Chairman, Engineering Committee, National Research Council	New York
Garrison, Frank Lynwood	Chairman, U. S. Manganese Commission	Philadelphia
Gudeman, Edward	Emergency Fleet Corporation	Chicago
Henderson, George R.	State Advisory Engineer, Federal Fuel Administration for Pennsylvania	Philadelphia
Honaman, R. Karl	Associate Physicist, Bureau of Standards	Washington
Hornor H. A.	Electrical expert for Industrial Training, Emergency Fleet Corporation	Philadelphia
Hoskins, Wm.	Consulting Chemist, Advisory Committee, Bureau of Mines; Associate Member, Naval Consulting Board	Chicago
Humphreys, Rich'd L.	Director of Building Materials, Building Materials Div., War Industries Board	Washington
Hyde, Edward P.	National Research Council, Sub-Committee on Monocular vs. Binocular Field-Glasses (Chairman)	Cleveland
Insull, Samuel	Chairman, Illinois State Council of Defense	Chicago
Keller, Harry F.	Assistant Director of Allied Bodies, Department of Public Safety of Penna.	Philadelphia
Kennelly, A. E.	Conducting special course in radio-engineering for the U. S. Signal Corps, in conjunction with Prof. E. C. Chaffee	Harvard Univ.
Lloyd, E. W.	Asst. Secretary, Illinois State Council of Defense	Chicago
Merrick, J. Hartley	Director, Bureau of Camp Service, Penna. Div., American Red Cross	Philadelphia
Milne, David	Treasurer, American Red Cross, General Hospital No. 1	Philadelphia
Morris, Effingham B.	Treasurer, Committee of Public Safety, State of Pennsylvania	Philadelphia
Nichols, Carroll B.	Fuel Administration	Washington
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Osborne, L. A.	Member, National War Labor Board	Washington
Penrose, R. A. F., Jr.	Member of Geology Committee of the National Research Council	Philadelphia
Picolet, L. E.	Civilian Personnel, Trench Warfare Section, Ordnance Office	Washington

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Rapp, Isaiah M.	Special Investigator of Weights and Measures for the U .S. Food Administration	Norman, Oklahoma
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Sperry, Elmer A.	Member of Naval Consulting Board	Brooklyn, N.Y.
Sprague, Frank J.	Member of Naval Consulting Board, Chairman, Committee on Electricity and Shipbuilding	
Steinmetz, Joseph A.	Member National Research Council, Engineering Division	Washington
Stern, Max J.	Supervising Surgeon, Merchant Shipbuilding Corporation	Philadelphia
Swenson, Magnus	Federal Food Administrator for Wisconsin; Chairman, State Council for Defense	Madison, Wis.
Taggart, Walter T.	Consulting Chemist, Nitrate Division, Ordnance Department	Philadelphia
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Thomson, Elihu	National Research Council in coöperation with Council of National Defense	Swampscott, Mass.
Turnbull, William F.	Department of Labor	Washington
Wadleigh, Francis R.	Emergency Fleet Corporation	Philadelphia
Warwick, J. F.	Bethlehem Loading Co.	Mays Landing, N. J.
Wharton, Henry	Y. M. C. A.	France

Please send additional information and corrections to the Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting Held Wednesday, December 4, 1918.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 4, 1918.

DR. H. JERMAIN CREIGHTON *in the Chair.*

The following report was presented for first reading:

No. 2727: Stabilized-Platform Weighing Scale of Novel Design.

The following report was presented for final action:

No. 2723: Prestwich Patent Fluid Gauge. Recommended that the Edward Longstreth Medal of Merit be awarded to John Alfred Prestwich, of Tottenham, London, England.

GEORGE A. HOADLEY,
Acting Secretary.

SECTIONS.

Electrical Section.—A joint meeting of the Section and the Philadelphia Section, American Institute of Electrical Engineers, was held in the Hall of the Institute on Thursday evening, November 7, 1918, at 8 o'clock. As the Chairman of the Electrical Section was the speaker of the evening, the meeting was presided over by Mr. George R. Henderson.

Mr. W. C. L. Eglin delivered an illustrated lecture on "The Power Company." Mr. Eglin began by giving figures showing that the electrical industry ranked fourth according to the value of its products. He then showed by figures and graphic illustrations how the industry grew in number of employees, size of generating units and output. Particular reference was made to the system of the Philadelphia Electric Company, showing by means of a diagram the A. C. and D. C. distributing systems, high-tension transmission lines, the street railway supply and the railroad electrification. Views were also shown of the newest types of generating stations in various parts of the country.

On account of the meeting occurring during the evening of the day on which it was rumored that the armistice, terminating the World War, had been signed, the attendance was unusually small. After a brief discussion the meeting adjourned.

H. CALVERT,
Secretary.

Section of Physics and Chemistry.—A joint meeting of the Section and the Philadelphia Section, American Chemical Society, was held in the Hall of the Institute on Thursday evening, December 5, 1918, at 8 o'clock, with Dr. Harry F. Keller in the chair. The minutes of the previous meeting were approved as read. The program for the meeting of December 10th was announced.

Edgar F. Smith, Ph.D., Sc.D., Chem.D., Litt.D., L.H.D., LL.D., Blanchard Professor of Chemistry in the University of Pennsylvania, and Provost of the University, delivered a lecture on "Chemistry in Old Philadelphia," describing the life and contributions to chemistry of deNormandie, Rush, Priestley, Hutchinson, Woodhouse, Coxe, the Seyberts, T. P. Smith, Cooper, Troost, Keating, Cloud, and Hare. A résumé was given of the growth of industrial chemistry in Philadelphia. The lecture was illustrated with lantern slides, and the balances of Priestley and the lock and key of his home were exhibited. Several members and visitors participated in the discussion. A vote of thanks was tendered Provost Smith, and his paper was referred for publication.

Mr. Hance introduced Captain S. N. Lemon, of the Canadian Army, who described the use of gas in warfare by the Germans. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Tuesday evening, December 10, 1918, at 8 o'clock, with Dr. Harry F. Keller in the chair. The minutes of the previous meeting were read and approved.

Joseph W. Richards, Ph.D., Professor of Metallurgy in Lehigh University, Secretary of the American Electrochemical Society, and Member of the U. S. Naval Consulting Board, gave an address on "The Vapor Tensions of the Metals." A résumé was given of the available data concerning the vapor tensions and the boiling points of the metals, and of the analogies between the vapor tensions of metals and of other elements and compounds. Methods were outlined for the calculation of the vapor-tension curves of metals in both the solid and the liquid state. The value of this information in pure science, in metallurgy, and in various uses of the metals was discussed and illustrated.

The communication was discussed by Messrs. Penrose and Clamer, Professor Snyder, Drs. Alleman and Richards, and others. On motion of Dr. Walton Clark, the paper was referred for publication. A vote of thanks was tendered Doctor Richards, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 11, 1918.)

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MR. JOSEPH BUNFORD SAMUEL, Retired Iron Merchant, 1609 Spruce Street, Philadelphia, Pennsylvania.

MR. LESLIE D. SMITH, Chemist, 309 South Frazier Street, Philadelphia, Pennsylvania.

NON-RESIDENT.

DR. JOHN HUNT WILSON, Professor of Chemistry, Lafayette College, and for mail, 531 Cattell Street, Easton, Pennsylvania.

ASSOCIATE.

MR. RICHARD ASHBY MARRIOTT, Student, Rensselaer Polytechnic Institute, and for mail, Young Men's Christian Association, Troy, New York.

CHANGE OF ADDRESS.

MR. THOMAS BILYEU, in care of Astoria Marine Iron Works, Astoria, Oregon.

MR. W. J. CRAGO, in care of Fajardo Sugar Company, Fajardo, Porto Rico.

MAJOR VICTOR LENHER, 158 Summit Avenue, Madison, Wisconsin.

MR. FREDERICK W. SALMON, 274 Wellington Avenue, Auburn, Providence, Rhode Island.

MR. CARL D. ULMER, 162 East Water Street, Middletown, Pennsylvania.

MR. HENRY W. WILSON, 909 Clinton Street, Philadelphia, Pennsylvania.

LIBRARY NOTES.

PURCHASES.

American Society for Testing Materials.—A. S. T. M. Standards. 1918.
CROY, HOMER.—How Motion Pictures are Made. 1918.
DURAND, W. F.—Practical Marine Engineering. Ed. 7. 1918.
DYSON, C. W.—Screw Propellers. 2nd ed. 2 vols. 1918.
Flying Book.—Edited by W. L. Wade. 1918.
GREGORY, H. E., ed.—Military Geology and Topography, 1918.
KLEIN, A. W.—Kinematics of Machinery. 1917.
National Association of Railroad Commissioners.—Proceedings, Vol. 29. 1917.
RICHARDS, J. W.—Metallurgical Calculations. 1918.
SEVERANCE, H. O., comp.—Guide to the Current Periodicals and Serials of the United States and Canada. Edition 3. 1914.
SLEEMAN, C. W.—Torpedoes and Torpedo Warfare. 1880.
United States Catalogue. Supplement.—Books published 1912–1917.
WHELEN, TOWNSEND.—The American Rifle. 1918.

BOOK NOTICES.

BIBLIOGRAPHY OF AMERICAN LITERATURE RELATING TO REFRIGERATION, WITH SYNOPSIS OF PAPERS AND REPORTS COVERING THE YEAR 1915. Compiled by Peter Neff under the direction of the Committee on Papers and Lectures of the American Association of Refrigeration. 107 pages, paper covers. 8vo. Chicago, Illinois, published by the Association.

The large amount of valuable information contained in the files of technical periodicals, much of which is available only by laborious consultation of yearly indexes, offers an extensive field for the work of the bibliographer which has not yet been adequately covered. The author of this compilation and the society which sponsored it are rendering the profession a valuable service in publishing a bibliography of current literature on refrigeration.

The work is more than a bibliography, it contains also a section devoted to book reviews, and a collection of abstracts, the latter covering 76 pages. In the bibliographic section, brief synopses of subject matter are given. The book reviews are unabridged. The abstracts give at considerable length a very satisfactory résumé of the topics recorded. Indexes under title, subject and author are included.

The Committee state that if the present volume meets with approval, it is their purpose to publish a volume for each succeeding year, and to prepare a synopsis of all literature published on ice and refrigeration previous to 1915. It is stated that the appearance of the volume has been delayed by war conditions. The 1916 Bibliography has been delayed for the same reason, but is now in press and will be issued at an early date.

The work can scarcely fail to prove of great value, and it is to be hoped that the Society will be induced to carry out the comprehensive plan outlined.

LUCIEN E. PICOLET.

PRACTICAL PHYSIOLOGICAL CHEMISTRY. By Philip B. Hawk, M.S., Ph.D., Professor of Physiological Chemistry and Toxicology in Jefferson Medical College. Sixth edition, revised and enlarged, 634 pages, contents and index, four additional full-page colored plates and one hundred and eighty-five figures, of which twelve are in colors, 8vo. Philadelphia, P. Blakiston's Son & Company, 1918. Price, $3.50.

A book which has in eleven years gone through six editions, including two reprintings, must find a want and meet it satisfactorily. Indeed, every one who is familiar with Doctor Hawk's work is fully aware of its merit. Physiologic chemistry is a rapidly growing phase of science, and is already so complex as to require a great deal of close study and accurate experimentation to secure any familiarity with it. This book will be a highly satisfactory guide to both the student and practical chemist. One of the most interesting chapters is that on enzymes. A vivid synopsis is given of our present knowledge (and want of knowledge) on this important subject. The presswork, printing, proofreading, and especially the color-plate work, are all excellent, and the text is throughout clear and explicit. The book is another evidence of our enfranchisement from using as text-books mere translations from foreign authors.

HENRY LEFFMANN.

INTRODUCTION TO ORGANIC CHEMISTRY. By John Tappan Stoddard, Professor of Chemistry at Smith College. Second edition, 411 pages, contents and index, 12mo. Philadelphia, P. Blakiston's Son & Company, 1918. Price, $1.50 net.

This is a readable and concise summary of the leading data of organic chemistry as now taught in American schools. The endeavors of the author as expressed in the preface are well met, facts and theories being presented "simply, directly and connectedly, so that the student may gain a clear idea of the principles of organic chemistry and its relations to general chemistry." The text is relieved of much detail by tables giving names, formulas and properties of many groups of compounds. The treatment of the important groups of alkaloids and protein seems too brief. The section on enzymes is more satisfactory, but should have been put with proteins. The book is well printed with clear type, but the margins are rather narrow, and, in the copy in the reviewer's hands, several signatures have been obliquely trimmed, giving an unpleasant appearance to the page.

HENRY LEFFMANN.

THE CHEMISTS' POCKET MANUAL. By Richard K. Meade, M.S. Third edition, 514 pages and index, 16mo. Easton, Pa., The Chemical Publishing Company, 1918. Price, $3.50.

This compact book, convenient for laboratory use, contains a large amount of information, principally, of course, as with all such manuals, in the form of tables and constants. Considerable space is, however, devoted to analytic methods along industrial lines, many of the recent methods developed by American chemists in the great industrial districts of the eastern part of the country being included. The principal value of such a book will be in the

selection of subjects, the freedom from typographic errors and clearness of printing. The volume in question meets these requirements very well. It is probable that the methods are given too briefly in some cases, and it is doubtful if laboratory workers seeking information on analytic methods will consult a work of this type, but rather the standard works. It is for the tables that the book will be most used, yet there is a large amount of useful information on standard analytic methods presented. On page 310 "anilin" is accidentally spelt "analine," and on page 436 a solution of "hydrochlorid of naphthylamin" is given as one of the reagents for detecting nitrates, while on page 297 the reagent is given as "alpha-naphthylamin acetate." The latter is the correct form.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

University of Kansas, Bulletin: Engineering Bulletin No. 10. The Present Development of Transmission Lines in Kansas, with Appendix: The Calculation of Iron Wire Lines, by F. Ellis Johnson. 53 pages, illustrations, plate, map, 8vo. Lawrence, Kansas, University Engineering Experiment Station, 1918.

United States Tariff Commission: Tariff Information Series, No. 8. The Brush Industry. Commercial and Industrial Conditions in the United States and in Foreign Countries. Tariff Laws Affecting Brushes. Court and Treasury Decisions. 77 pages, 8vo. Washington, Government Printing Office, 1918.

U. S. Bureau of Mines: Monthly Statement of Coal-mine Fatalities in the United States, August, 1918. List of Permissible Explosives, Lamps, and Motors Tested prior to September 30, 1918; compiled by Albert H. Fay, 27 pages, 8vo. Bulletin 129, The Fusibility of Coal Ash and the Determination of the Softening Temperature; by Arno C. Fieldner, Albert E. Hall and Alexander L. Feild. 146 pages, illustrations, plates, 8vo. Bulletin 171. Mineral Technology 23. Melting Brass in a Rocking Electric Furnace; by H. W. Gillet and A. E. Rhoads. 131 pages, illustrations, plates, 8vo. Washington, Government Printing Office, 1918.

North Carolina Geological and Economic Survey: Economic paper No. 48. Forest Fires in North Carolina During 1915, 1916 and 1917, and Present Status of Forest-fire Prevention in North Carolina; by J. S. Holmes, State Forester. 97 pages, 8vo. Raleigh, State printers, 1918.

Introduction to Organic Chemistry, by John Tappan Stoddard. 2nd edition, 423 pages, 12mo. Philadelphia, P. Blakiston's Son & Company, 1918. Price, $1.50.

CURRENT TOPICS.

Renovation of Discolored Arc-lamp Globes. A. HERTZ. (*Electrical World*, vol. 72, No. 20, p. 935, November 16, 1918.)—It is common knowledge that in certain cases after new glassware has been installed on street-lighting units, a very obnoxious discoloration has occurred in a comparatively short time. The glassware which suffers most is that subjected to the rays from arc lights rich in short ray-lengths, such as the magnetite arc. The most common discoloration is purple which is present only where the artificial light strikes the glassware, such places as are shielded from the lamp rays being clear, even after long use, aside from the coloring brought about by the rays of the sun. The amount of the discoloration depends upon three factors: (1) The composition of the glass; (2) the amount of violet and ultra-violet light present; (3) the time of exposure.

The glass subject to this discoloration usually contains some form of iron, commonly Fe_2O_3, in some cases amounting to 6 per cent. This glass in its natural state is colored slightly green, and various means have been tried for neutralizing this coloration. Manganese compounds are found to be commercially most satisfactory for this purpose. Purple, the characteristic color of manganese, when added to the green in the original glass, produces a very thin black cloud which absorbs some of the light, usually 10 to 15 per cent. Under the action of certain light, the purple manganese color itself becomes prominent, entirely over-balancing the green in the iron. Since this purple color entirely penetrates the body of the glass, it is at once apparent that a pickling or washing process is useless. Having observed that the color could be removed from pieces of broken globes by heating, further experiments were made, and it was found that these globes could be entirely cleared up by a careful heat-treatment. An annealing process carried out at a temperature of 900° F. was found to remove the color without causing softening or distortion of the globes. The annealing seemed to reform the manganese compound into its original condition so that the glassware again became clear.

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The Board of Trustees was formed in accordance with the following By-Laws passed in the year 1887:

> All Real and Personal Estate of the Institute which may hereafter be acquired by voluntary subscription or devise, bequest, donation, or in any way other than through its own earnings or by investment of its own funds, saving where the donors shall expressly provide to the contrary, shall be taken as acquired upon the condition that the same shall be vested in a Board of Trustees, who shall be appointed in the manner hereinafter indicated. Unless the title to such property shall be directly vested in said Board of Trustees by the donors, the Institute, by deed attested by the President and Secretary, which they are hereby authorised to execute and deliver, shall forthwith convey the same to said Trustees, who shall hold it in trust for the purposes specifically designated by the donors; or, if there shall be no specific designation, for the benefit of the Institute in the way and manner hereinafter provided, so that the same shall not, in any event be liable for the debts of the Institute.

This method of separating the *body holding* the principal of the various funds from the Board of Managers, the *spending body*, is an original idea of The Franklin Institute and it is hoped it will appeal to friends who may desire to create funds to further the objects of the Institute, and the various branches of science in which they may be interested.

MEMBERSHIP.

Terms and Privileges.

THE MEMBERSHIP OF THE INSTITUTE is divided into the following classes, viz.: *Resident Members, Stockholders, Life Members, Permanent Members, Non-resident and Associate Members.*

Any one interested in the purposes and objects of The Institute and expressing a willingness to further the same may become a member when proposed by a member in good standing and elected by the Board of Managers.

TERMS.—Resident members pay Fifteen Dollars each year. The payment of Two Hundred Dollars in any one year secures Life Membership, with exemption from annual dues.

STOCK.—Second-class stockholders pay an annual tax of Twelve Dollars per share, and the holder of one share is entitled by such payment to the privileges of membership.

PRIVILEGES.—Each contributing member (including non-residents) and adult holder of second-class stock is entitled to participate in the meetings of The Institute, to use the Library and Reading Room, to vote at the Annual Election for officers, to receive tickets to the lectures for himself and friend, to attend the Section meetings and to receive one copy of the JOURNAL *free* of charge, except associate members, who may not take part in elections.

PERMANENT MEMBERS.—The Board of Managers may grant to any one who shall in any one year contribute to The Institute the sum of One Thousand Dollars a permanent membership, transferable by will or otherwise.

NON-RESIDENT MEMBERS.—Newly elected members residing permanently at a distance of twenty-five miles or more from Philadelphia may be enrolled as Non-resident Members, and are required to pay an entrance fee of Five Dollars, and Five Dollars annually. Non-resident Life Membership, $75.00.

Contributing members, if eligible, under the non-resident clause, on making request therefor, may be transferred to the non-resident class by vote of the Board of Managers, and are required to pay Five Dollars annually.

ASSOCIATE MEMBERS.—Associate members are accorded all the privileges of The Institute, except the right to vote or hold office, upon the payment of annual dues of Five Dollars. This class of membership is limited to persons between the ages of seventeen and twenty-five years. Upon reaching the age limit they become eligible to the other classes of membership.

RESIGNATIONS *must be made in writing, and dues must be paid to the date of resignation.*

For further information and membership application blanks address the SECRETARY of THE INSTITUTE.